



UNITED STATES AIR FORCE RESEARCH LABORATORY

Unit Type Code Development, Tailoring, and Optimization (UTC-DTO) Phase 2 Final Report

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FOR THE COMMANDER



ALBERT S. TORIGIAN, Lt Col, USAF
Deputy Chief
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FINAL REPORT

UNIT TYPE CODE - DEVELOPMENT, TAILORING, AND OPTIMIZATION (PHASE 2), LOAD PLANNING AUTOMATION

EXECUTIVE SUMMARY

Supporting the overall Logistician's Contingency Assessment Tool (LOGCAT) project, the Unit Type Code - Development, Tailoring, and Optimization (UTC-DTO) task consisted of two phases. Phase 1 reviewed the feasibility of automatically developing and tailoring UTCs. Phase 2 consisted of the Load Planning Automation Study which addressed the feasibility of automatically optimizing the building of 463L aircraft cargo pallets and a concept paper which presented a possible system concept. This paper, the first of two technical reports for Phase 2 of the UTC-DTO project, documents the completion of the UTC Load Planning Automation Study performed by Dynamics Research Corporation. This document is the integration of another technical report and concept paper as well as necessary updates to ensure completeness and accuracy.

The study and concept paper were completed as part of Delivery Order 237 on Contract No. DCA100-94-D-0014. The study documents the required review of policy and procedures, along with existing and planned systems to determine the feasibility of UTC load planning automation optimization for 463L pallets and focuses on the deployment aspect of pallet building by unit augmentees rather than the transportation functional experts. Only the impacts of using military tactical and strategic airlift aircraft were reviewed. Specifically, the C-130, C-141, C-5, C-17, KC-135, and KC-10 aircraft were included in the Statement of Work. Civil Reserve Air Fleet (CRAF) airlift were not identified as part of the study.

This document contains three major sections. Section 1 covers the Load Planning Automation Study, Section 2 the Concept Paper, and Section 3 the overall Recommendations. The Introduction section describes why and how the research was done and provides the principal results, conclusions, and recommendations. It also introduces the report and presents general background material.

FINAL REPORT

UNIT TYPE CODE - DEVELOPMENT, TAILORING, AND OPTIMIZATION (PHASE 2), LOAD PLANNING AUTOMATION

INTRODUCTION

OVERVIEW

This study was undertaken in support of the overall Logistician's Contingency Assessment Tool (LOGCAT) project, the Unit Type Code - Development, Tailoring, and Optimization (UTC-DTO) task, and consisted of two phases. Phase 1 reviewed the feasibility of automatically developing and tailoring Unit Type Codes (UTCs). Phase 2 addressed the feasibility of automatically optimizing the loading of 463L aircraft cargo pallet loads. The focus of Phase 2 was on the deployment aspect of pallet building by unit augmentees rather than the transportation functional experts.

Section 1 of this report documents the required review of policy and procedures along with existing and planned systems to determine the feasibility of UTC Load Planning Optimization Automation for 463L pallets. Section 2 presents a potential system concept (i.e., the Concept Paper). Section 3 presents the overall recommendations resulting from the study and the Concept Paper.

Only the impacts of using military tactical and strategic airlift aircraft were reviewed, specifically, the C-130, C-141, C-5, C-17, KC-135, and KC-10 aircraft. CRAF airlift was not part of the study. The methods used for the study consisted of examining the feasibility of automating the load planning for 463L pallets by UTC from policy, technical, and practical points of view by:

- a. Researching publications to determine the current policy and procedures
- b. Identifying and researching existing systems and tools which were related to the effort's objectives or appeared to support aspects of the objectives
- c. Identifying and researching applicable technologies and methodologies
- d. Researching and identifying algorithms for possible use
- e. Estimating a return on investment for the automation

It was determined that the major cargo aircraft related automated planning systems, Automated Air Load Planning System (AALPS), Airlift Loading Model (ALM), Dynamic Analysis and Replanning Tool (DART), and Marine Air Ground Task Force II (MAGTF II), offered many sophisticated capabilities to improve the speed and accuracy of deployment planning. However, none of these

specifically addressed the loading of pallets, either optimally or otherwise, although some did provide capabilities for creating and modifying aircraft loading plans.

Additionally, from research performed on the palletization process and the available computer-based techniques, it appears that building and implementing an automation tool, hereafter referred to as the Automated Assistant, is both technically and practically feasible. Research has shown that there are points in the packing process where technology insertion would lead to significant benefits. It also appears that models do exist that could be tailored to the UTC optimization problem. Further research is required to produce a model that will adequately capture the goals and constraints of packing 463L pallets.

The study led to the conclusion that optimal models in the strict mathematical sense may not be achievable, but techniques that will have a significant payoff on key optimization measures can be applied. Implementation of an Automated Assistant can substantially increase utilization of the space available on 463L pallets. The expectation is that the average number of pallets used to transport the analyzed force package represented by Unit Type Code "3FKM3," an 18 Primary Authorized Aircraft (PAA) F-16 package, could be reduced by nearly 20%. This percentage is derived by assuming near perfect optimization (height only) of all pallets listed in the Logistics Plan (LOGPLAN) and then subtracting the resultant number of pallets from the original number. This reduction assumes the use of technology as well as changes in policy. In addition, it is expected that less time will need to be spent building or rebuilding pallets because the Automated Assistant will generate higher quality loading plans faster than through manual methods.

The key area that needs to be addressed is the development of a suitable modeling technique for "optimized" pallet loading. A number of partially acceptable solutions can be used as a starting point. Research to produce a technique that can adequately model the problem and generate solutions in reasonable amounts of time should continue. Follow-on research should also continue to investigate methods for displaying the results of the model. It may be necessary to produce loading diagrams "on-the-fly" to give to packers so the computer generated loading plan can actually be accomplished.

Research should also consider appropriate methods of change management. When technology is inserted into an existing process, it should be done in a way that will make it acceptable to users and not be viewed as another bottleneck in an already time-critical process. It would also be beneficial to conduct further research into some additional process details, such as the specific rules for loading hazardous cargo; the implications of pallets being loaded on ramp positions in aircraft; and any considerations that may arise when multiple destinations are required for deploying units.

In conclusion, an Automated Assistant for loading 463L pallets can and should be designed and implemented. The deployment planning personnel contacted acknowledged its potential value, and the job is feasible from both technical and practical points of view. The concept for a 463L pallet load planning optimization toolkit, as presented in Section 2, would appear to significantly improve the speed, accuracy, flexibility, asset visibility, and training when compared to the current manual process. Moreover, all of the above factors/areas are significant contributors to readiness. Therefore, it is reasonable to conclude that automating the current process could help improve readiness and the ability of units to deploy their UTCs.

Subject: The Load Planning Automation Study (Section 1) documents the feasibility of optimizing pallet configuration using the 463L aircraft cargo pallet (HCU-6/E, Federal Stock Number 16700008204896CT). The 463L PalletLoad Planning Optimization Concept presented in Section 2 focuses on a concept for a load planning optimization system to be used at the UTC level for building (i.e., “packing”) 463L aircraft cargo pallets.

Purpose: The purpose of this study was to determine the feasibility of automatically ascertaining the optimal way to load equipment onto a 463L pallet. This includes a user-friendly interface that would allow pallet builders to rapidly re-plan pallet loading configurations for changes in aircraft availability, easily specify certain equipment items that must be on the pallet, and identify all hazardous material packing requirements. Load planning automation will ensure that pallet loading results in equipment packing on the minimum number of pallets. Another purpose of the study was to ensure that after equipment is loaded onto a pallet, the pallet conforms to any dimensional, center of gravity, or other requirements of the anticipated transport aircraft.

Units/Functions and UTCs: Due to time and funding constraints, the overall effort was scoped to a single fighter Mission, Design, Series (MDS), the F-16C/D, with the assumption that the processes could be readily ported to other aviation and support UTCs. The F-16 C/D UTC 3FKM3 and two direct-support UTCs (HFBZP and HFAGC) were used to keep the study in line with the fighter wing/base-level focus of the overall project effort. 3FKM3 represents an independent 18 PAA F-16 C/D squadron. HFBZP is an external tank build-up capability required to deploy with the 3FKM3 UTC. HFAGC is an intermediate level UTC which includes the remaining organizational off-equipment capabilities. Again, the tasking profile (timeline and funding) restricted the options of units and functions to visit and interview. Consequently, only local units were contacted for visits and in-person interviews. Telephone

calls accounted for the remainder of contacts. The 88 ABW/LGT and the 178 Fighter Group (Springfield-Beckley MAP, OH) were identified as logical local sources of information regarding operations, deployment, planning, training, and maintenance functions involved with pallet building. In addition, telephone interviews were conducted with HQ USAF/LGXX, HQ ACC/LGXRD, HQ AMC/DOZE and DOJC functional experts. Because of its availability and appropriateness, Logistics Detail (LOGDET) data for the 3FKM3 UTC used in Part 1 of UTC-DTO was used to analyze echelon, increment, and pallet use. More specifically, LOGPLAN data from the 388 TFW Hill AFB, UT was used. This was in keeping with the overall project focus on aviation UTCs that may be tasked for short-notice/crisis situations requiring fighting capability or support for an operation other than war (OOTW) scenario. Moreover, airlift aircraft considered in the study were limited to the military: C-130, C-141, C-5, C-17, KC-135, and KC-10.

Issues Acknowledged: Most current deployment planning systems are oriented to Major Command (MAJCOM) and/or Air Staff and do not necessarily solve wing/base-level problems. Moreover, the orientation of most of the tools and systems available are for deliberate planning (OPLAN) versus short-notice/crisis action planning (NOPLAN). There is an expressed and supported need for the application of information technology tools and methodologies to enable the wing/base-level planner and unit/shop or section deployment manager to accomplish the job more accurately and efficiently. The Enhanced Contingency Logistics Planning and Support Environment (ECLiPSE) study concluded that the systems/methods of current deployment planning and execution functions can be improved significantly by the automation, reengineering, and insertion of existing, emerging or new technology and methodologies.

Risk: Risk involved in this general functional area revolves around the near continuous changes in forces, missions, and roles. Coupled with the almost infinite number of systems/tools and the number of stakeholders involved in the planning and transportation processes, this creates a moving target that is difficult for technology-based solutions to completely cover. In this environment, it could be very easy to "overlook" a system, tool, technology, methodology, or algorithm that is being used or developed and could be vital in establishing feasibility. Additionally, there are multiple focal points conducting related efforts to which stakeholders/developers must go for information. Moreover, technological advances occur at a phenomenal rate, and again, there is always the possibility of inadvertently overlooking applicable technologies or methodologies due to the sheer number of information sources. Recognizing

this, the investigating team took great care to cover all major military sources available locally, as well as a significant academic/commercial sampling.

Level: The level addressed by this effort is the wing/base and below. The diagram in Figure 1 shows potential LOGCAT connectivity with other wing/base-level systems [Integrated Deployment System (IDS) and Deployment Management System (DeMS)].

Background: The technical report "ENHANCED CONTINGENCY LOGISTICS PLANNING AND SUPPORT ENVIRONMENT (ECLIPSE): THE VISION," (AL/HR-TR-1995-0005, January 1995), documented the existing environment and the possibilities of identifying and evolving potential solutions to complement related existing, emerging, and projected systems. UTC-DTO was identified as a possible tool for use within the overall system that could help wing/base-level planners accomplish their UTC-based tasks in a more efficient and effective manner.

Overall Project Description: LOGCAT is a vision for improved wing-level deployment planning and re-planning. Currently, the LOGCAT Vision is comprised of four integrated initiatives: Survey Tool for Employment Planning (STEP); UTC-DTO; Beddown Capability Assessment Tool (BCAT); and Logistics Analysis to Improve Deployability (LOG-AID). STEP will use advanced integration of computer hardware and software to automate the collection, storage, and retrieval of deployment site survey information. BCAT will use advanced database design to compare deployment site force beddown capabilities against the deploying forces' beddown requirements and produce a list of resource shortfalls. UTC-DTO will use advanced software to automatically develop and tailor UTCs based on individual deployment scenarios and optimize the packing of UTC equipment on 463L aircraft cargo pallets. LOG-AID is a requirements analysis that will study the wing-level deployment process firsthand and discover improved processes and technologies to provide order of magnitude improvements to the wing-level deployment processes. Figure 1 shows the relationships amongst LOGCAT concepts.

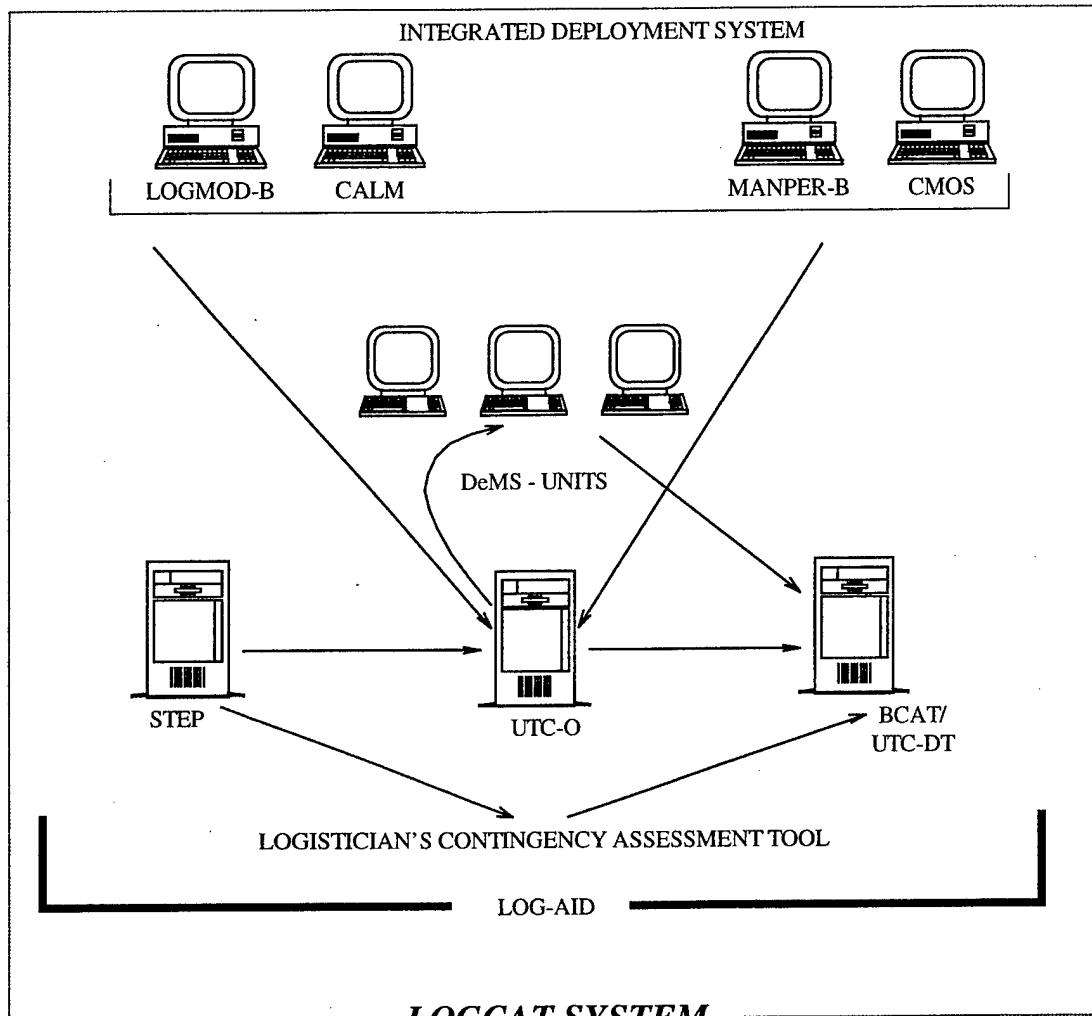


Figure 1 - LOGCAT (ECLiPSE) Overview

LOGCAT (ECLiPSE)

The ECLiPSE Vision documented the first technical effort associated with the LOGCAT research and development (R&D) initiative. The LOGCAT goal was established in the ECLiPSE Vision report as, “demonstrate how advanced technologies can improve the quality and timeliness of wing logistics planning and replanning for short-notice contingency operations.” The effort’s goal was to “develop preliminary concept specifications for the operational components and relevant information technologies for a notional LOGCAT system.” Three projects, two systems, and one study were proposed in the Vision report; DISE (now the Survey Tool for Employment Planning), Unit Type Code-Development, Tailoring, and Optimization, and Logistics Analysis to Improve Deployability.

Subsequently, and as a result of mutual interest shared by the Air Force Logistics Management Agency (AFLMA) and Armstrong Laboratory (AL), a fourth project (the third system), Beddown Capability Assessment Tool, was added to the overall program. These LOGCAT projects are described in the following paragraphs.

Survey Tool for Employment Planning (STEP): STEP has three components. The first component is a centrally-located Employment Knowledge Base (EKB) that will store deployment information such as site maps and surveys, lessons learned, and related war reserve materiel information. The second component will assist planners in collecting deployment site information to populate the EKB. The third component will use the information in the EKB through a Graphical User Interface (GUI), along with other information, to analyze beddown requirements with respect to beddown site resources. As described in the completed LOGCAT (ECLiPSE) Requirements Study, the envisioned real-time deployment information will be useful for numerous deployment analysis tasks. One of these is to feed analytic "models" of the operating environment at the deployed location. These "models" will be used in BCAT to define and specify beddown requirements with respect to deployment site resources.

STEP will use knowledge engineering and state-of-the-art multimedia technologies to improve the planning process. Knowledge-based technology will be emphasized to provide expert assistance for performing a site survey and throughout the reception and deployment planning process. Special attention will be paid to how the wing-level deployment lessons-learned database will be structured to allow growth in both the rules and expert knowledge as experience is gained from exercise and actual deployments. Multimedia technology will provide wing planners with better information on beddown sites. This effort also involves investigating the feasibility of using satellite communications to automatically update the STEP deployment site database at execution time.

The users of this system are varied. The primary users will be wing/base-level planners who are responsible for determining what equipment and personnel to deploy and reception planners who are responsible for determining what equipment, facilities, and supplies are required to support the forces identified in the Time Phased Force Deployment Data (TPFDD). Through distributed collaborative planning technologies, these users will communicate audio, visual, and textual information. Additional users of STEP are located at the MAJCOMs, Theater Commands, and the Logistics Readiness Center. Additionally, STEP could be expanded to include information from Army, Navy, United Nations, and allied forces bedding down at specific locations.

Beddown Capability Assessment Tool (BCAT): The purpose of the BCAT is to analyze and demonstrate the feasibility and usefulness of advanced computer software to perform force beddown planning. This effort will provide the capability for comparative analysis of weapon system support requirements and base-level support capabilities for effective beddown planning. The capability will also allow resource shortfalls or limiting factors (LIMFACs) which may drive support investment decisions at base-level to be identified. BCAT will demonstrate how the application and insertion of emerging technologies will benefit LOGCAT. Many of the concepts will be integrated with other LOGCAT components such as STEP.

BCAT will use Commercial-Off-the-Shelf (COTS) software to develop a database structure that will allow the user to enter beddown requirements in a standard format. Moreover, BCAT will have the capability to develop the ability to compare the UTC requirements database with the beddown base capabilities database and automatically generate a third database populated with all beddown considerations such as shortfalls, overages, potential LIMFACs, etc. As a result of a programmatic decision to include the development and tailoring portion of the UTC-DTO function under BCAT, the development and tailoring software will be done as part of BCAT.

Unit Type Code-Development, Tailoring, and Optimization (UTC-DTO): UTC-DTO is composed of two subcomponents, an automatic UTC development and tailoring capability and an automatic palletization optimization system. The development and tailoring subcomponent will automatically generate or tailor UTCs for a specific mission. The optimization subcomponent will automatically generate optimal pallet arrangements based on the tailored or complete UTCs.

Logistics Analysis to Improve Deployability (LOG-AID): LOG-AID will rigorously analyze the mobility and deployment process at the wing/base/unit-level from time of receipt of a TPFDD until the associated cargo and personnel are packed, prepared, and ready to board a conveyance to the mission area (see Figure 2). It will also recommend innovative processes and technologies to improve the current processes. Today's reality of reduced forward presence of United States forces abroad mandates the ability of U.S. forces to rapidly deploy to one or more areas of operation. Additionally, shrinking airlift resources and reduced manpower necessitate more effective and efficient use of our deployment resources. LOG-AID will help define improved processes and technologies to help logistics planners ensure that U.S. forces are able to meet future deployment scenarios.

Based on the results of the ECLiPSE Vision report and user input, it was determined that LOG-AID should be conducted to further investigate and refine user requirements and desires for future

deployment planning resources. LOG-AID will build on this study and any other pertinent literature and research. Since all logistics deployment planning is derived from operations deployment planning, this analysis will investigate operations deployment planning to gain an understanding of how it interfaces with and impacts on logistics deployment planning.

The information gathered to support LOG-AID will complement the original LOGCAT Vision and the HQ USAF/XOR Integration Definition (IDEF) Deployability Study. Information will be gathered from interviews with and observations of deployment and beddown planners at the wing-level and below, who perform deployment and beddown planning (either during real world deployments or exercises), information gathered from operations deployment and beddown planners, and a survey instrument that asks users for their requirements and desires for future deployment planning resources.

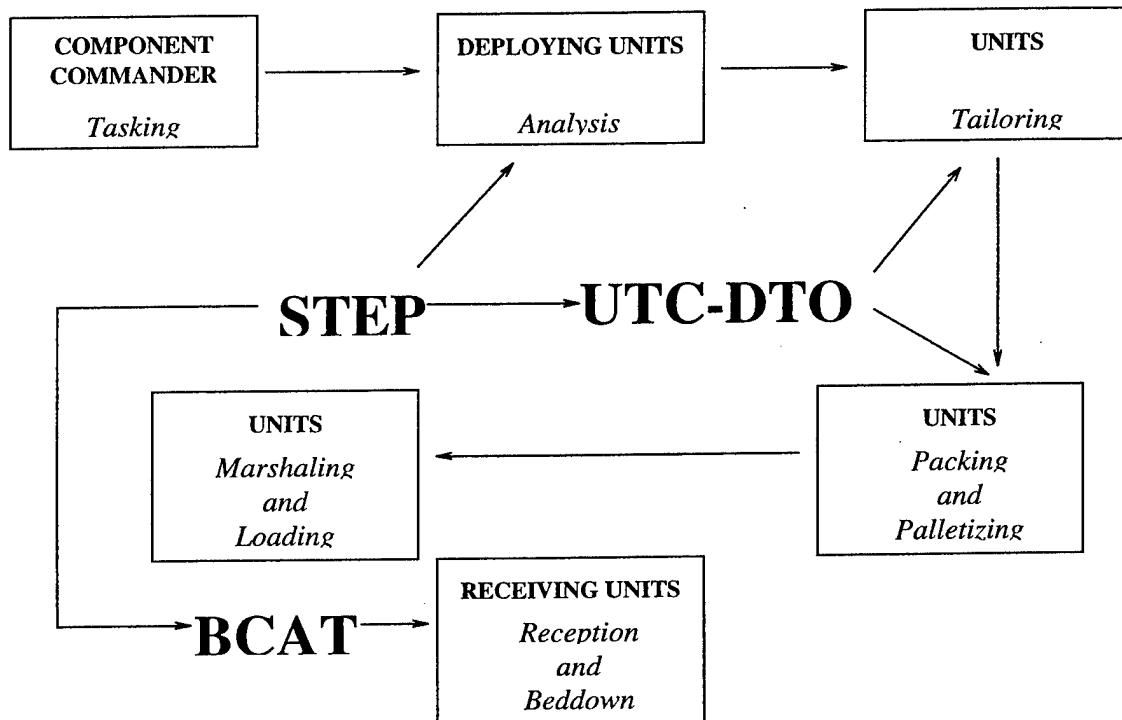


Figure 2 - The LOGCAT Systems Relationships

SECTION 1, LOAD PLANNING AUTOMATION STUDY

METHODOLOGY, ASSUMPTIONS, AND PROCEDURES

Methodology: The study methods used consisted of examining the feasibility of automating the load planning for 463L pallets by UTC from policy, technical, and practical points of view by researching publications to determine the current policy and procedures; identifying and researching existing systems and tools which were related to the effort's objectives or appeared to support aspects of the objectives; identifying and researching applicable technologies and methodologies; researching and identifying algorithms for possible use; and estimating a return on investment for the automation.

Contacts and systems identified and researched, along with the lessons learned from Phase 1 of the UTC-DTO effort, were used and made excellent points of departure for the Load Planning Automation Study. During this part of the study, team members used the capabilities of the Technical Documents Center and Wright-Patterson AFB publications libraries to obtain DoD and Air Force publications covering the deployment of forces and air transportation. The most applicable publications were obtained in hard copy or electronic media. Other applicable publications were reviewed and notes taken. Specifically, the applicable technical orders, technical manuals and formal training material were thoroughly reviewed. After establishing the written policy and procedures, visits were scheduled with local functionals or phone calls were made to offices or functions responsible for executing the established policy and procedures. These contacts served to verify the extent to which the written "word" was being followed by the functionals. These findings were then documented and are presented in this report.

Systems and Tools Research: Using the previous exposure to personnel with formal training and significant experience, along with systems related to the study area, an initial list of contacts, systems, and tools was compiled. This list was expanded several times as a result of discoveries made during research or individual referrals. Where possible, each system or tool on the list was further investigated to determine if it accomplished or impacted any of the desirable functions to automate and optimize 463L pallet load planning. The investigations included operating the system or tools available and reviewing technical documentation and/or reviewing technical papers or reports written by other investigators or evaluators. The findings were then documented and are presented in whole or part in this report.

Technologies and Methodologies: Based on recent experience of team members, the team identified technologies and methodologies that showed promise for the UTC 463L pallet load planning optimization application. The team also sought information on technologies and methodologies by attending seminars, acquiring relevant literature and papers, and making verbal inquiries. Through these materials, the team learned of technologies applicable to pallet load planning automation and formatted initial ideas on how the technologies could be inserted into the planning process. The findings were then documented and are presented in whole or part in this report.

Algorithms: In addition to examining systems and tools for possible use, the team researched both the academic and commercial sectors for problem-specific and universal algorithms. Of particular interest were algorithms dealing with the classical knapsack and cutting stock operations research problems. Research was accomplished using both manual and automated methods associated with libraries, electronic repository services, and the Internet. The results were then documented and are presented in this report.

Return on Investment: The team estimated the potential return on investment by assuming that all pallets for the selected UTCs were for the same destination and could be built to the maximum cube height of 96 inches and not exceed 7500 pounds. Savings estimates were in pallets used and C-141 equivalents saved.

Assumptions: The following major assumptions were made in conducting the Load Planning Automation Study:

3FKM3 LOGPLAN - This data is representative of current level of optimization accomplished.

Automation - The process can be less than full/complete; i.e., manual intervention by the logistics planner or unit deployment personnel is always an option/possibility.

Optimization - Obtaining maximum use of a 463L pallets load capacity. Using the maximum pallet dimensions, this would be a height of 96 inches and weight of 7500 pounds (can be less than 100 percent utilized).

Hardware/Software - Will be Open System Environment (OSE) compliant.

Legacy Data - Existing (legacy) data can and will be made available to LOGCAT systems.

MDS Portability - The F-16C/D UTC (3FKM3) palletization processes can be ported to any fighter Mission, Design, Series (MDS) and to most other (if not all) UTCs.

Personnel - Since manpower to accomplishing the wing mobility mission already exists in the various deployment functional areas, no additional manpower will be required in these areas as a result of employing LOGCAT systems. In fact, manpower requirements could potentially be reduced.

Security - Much of the data necessary for UTC Load Planning Automation will originate in classified databases/sources. Therefore, any system or tool proposed will either have a secure communications architecture for transmission or distribution functions, as well as secure equipment for data manipulation, distribution, storage, and printing, or have a method developed to present the needed information in an unclassified format.

Telecommunications - An existing telecommunications architecture/network (hardware and software) with sufficient capacity and capability to accomplish the desired transmission and distribution functions is available or will be developed.

Upward Compatibility - A 463L pallet optimized for the default aircraft (C-141) will fit onto a C-5 or C-17 aircraft without alteration.

Sources and Areas of Interest: In addition to researching publications and extracting relevant information, interviews were conducted (in person and via telephone) and facilities visited and examined. These fact-finding investigations enabled the team to accurately document information on roles and responsibilities, steps in the process, information sources (systems and publications), information flow and format, timing issues, quality issues, use of automated systems and tools, and exceptions. Although opinions, along with exercise and real-world experiences, were also readily solicited during interviews, care was exercised to ensure facts were separated from opinions. Moreover, where cited, opinions are labeled as such. Assessments (opinions) were specifically solicited and valued regarding the adequacy of current methods, areas for improvement, and the use and value of automation.

RESULTS AND DISCUSSIONS

Literature Search: Examination of applicable literature revealed an inferred policy of optimization in several Air Force publications. However, it was neither specific nor directive in nature. It was determined that a recent revision to AFI 10-401, Operation Plan and Concept Plan Development and Implementation, Chapter 6, Manpower and Equipment Force Packaging System (MEFPAK), reemphasized the need for consolidation, but again it was not directive in nature. Numerous publications and papers on the subject of Lean Logistics also expressed the need to reduce the logistics footprint. By

and large, the focus of these publications appeared to be geared more toward tailoring as a means to achieve consolidation or reductions as opposed to addressing the issue of reductions by optimizing the 463L pallet during the load planning function.

Existing Systems, Tools, and Algorithms: Research into and examination of the systems which the team were aware of or discovered during its search efforts and had access to revealed no known systems or tools that dealt specifically with the automation of 463L pallet load planning. Some work done in the area of algorithms could be used. Additionally, aspects of certain COTS applications, such as general-purpose mathematical programming systems (of which there are dozens commercially available) might provide some usable capability (i.e., the generation of optimal solutions) when used in conjunction with an appropriate model. Determining the possibility of extending the existing algorithms and applications would require extensive additional work.

Current Process: The unit commander oversees all cargo preparation in support of deployments. The current process for building 463L pallets starts with the unit or UTC tasking, which is defined further as a LOGPLAN in the Contingency Operation/Mobility Planning and Execution System (COMPES). This LOGPLAN contains the LOGDET for various tasked UTCs. Each increment of cargo must carry specific documentation according to cargo preparation directives. These include the AF Form 2279, pallet identifier or placard, Unit Line Number (ULN), UTC, deployment echelon, increment number, and mobility Transportation Control Number (TCN).

The cargo increment serves as the primary method of organizing material for deployment, and provides a means to establish a sequence for deployment and redeployment of deployment assets. The increment also allows a shorthand communication method of communicating for cargo shipments; provides a reference point for deploying planning to support of a specific operation plan; provides a reference point for tailoring deployment packages; provides a reference point for control of equipment processing during deployments; provides the basis planning element during aircraft load planning and cargo manifesting; and provides the reference point for establishing and maintaining standardization among units with like weapon systems.

The LOGDET is further reduced to packing listings for increment numbers for each deployment echelon. A deployment echelon is a UTC capability that commanders must deploy as a single entity. Deployment echelons facilitate deployment planning by identifying a unit's capabilities, material, and personnel requirements and designating the sequence of movement. Packing listings are produced by logistics planners and are distributed to the various shops having the responsibility to build pallets and/or

furnish cargo and equipment for the pallets being built. Pallets are “built up” by unit personnel who are augmentees with formal or on-the-job training.

Normally pallets are loaded with cargo to conform to the following minimum requirements: multiple layers on a single pallet; single UTC function on a single pallet; restricted hazardous cargo placement; and placing heavier items and strong containers on the bottom. Moreover, the pallet loading process is further impacted by several criteria which include multiple destinations, multiple types/classes of hazardous cargo, redeployment possibilities, type of transport aircraft, unit management preferences, cargo size, weight, shape, cargo packaging and containerization, and human and mechanical load handling limits.

Once the pallets are finished and ready for deployment, required notifications are made to the deployment management functions. When the base deployment function is ready to receive the “built up” pallet, they are called forward for inspection and marshaling. Normally, this is the first time that functional experts in pallet building become involved with the cargo being deployed. Up to the point of being accepted and marshaled, any change in the type of airlift aircraft that causes a pallet or pallets to be rebuilt is the responsibility of the deploying unit. If available, assistance can be and frequently is provided by base functional experts. Once the cargo is accepted and marshaled, the responsibility for pallet building due to a change in the type of aircraft shifts to the functional experts. If available, unit assistance in rebuilding is sometimes requested.

Given the process as described, it appears that there are two primary points at which optimization planning could be accomplished manually or automatically. The first is just prior to building the pallet and the second is at the point an aircraft type change is determined to require that the pallet be rebuilt. Where time allows such an action, manual planning would produce worthwhile results with the former when initially addressing a unit’s primary tasking. This would probably not be a good option in aircraft type changes because it is an obviously time-constrained situation. However, if any tailoring is required just prior to a deployment, the optimization planning would have to be redone. In this situation, time would not normally permit manual replanning. Thus, an Automated Assistant could be very valuable in both the replanning situation as well as replanning driven by airlift aircraft type changes. Additional benefits from automation would also be realized in the initial and proficiency training functions.

Airlift Aircraft: Figure 3 below presents focus aircraft of this aspect of the study. Basically, four types of aircraft were reviewed for impact on the automation of 463L pallet load planning. By and large, two factors impacted the degree of difficulty for automation: ramp access and interior design. Ramp positions were a variable for all four cargo role aircraft. The variables for the C-130 also involved wheel

well positions and comfort station access. No, or minimal, variables were envisioned for the three strategic airlift aircraft. The biggest challenges and largest number of variables were envisioned with the two tankers, due to the limited access openings and unusual interior configurations.

PRIMARY ROLE	MDS	RAMP ACCESS	IMPACT ON AUTOMATION
Tactical	C-130	Yes	Moderate
Strategic	C-141B	Yes	Minimal
Strategic	C-5A/B	Yes	Minimal
Strategic	C-17	Yes	Minimal
Tanker	KC-135	No	High
Tanker	KC-10	No	High

Figure 3 - Military Aircraft Included In Study

Civil Reserve Air Fleet (CRAF): Although CRAF aircraft were not a formal part of the study, numerous opinions rendered by augmentee personnel and functional experts suggest that replanning for CRAF aircraft would be the worst case scenario for optimization. Moreover, all personnel interviewed stated that their experience with CRAF aircraft during recent crisis situations was the most challenging. The consensus was that to be of maximum value, any Automated Assistant would have to include provisions for the CRAF aircraft.

Hazardous Cargo: Hazardous cargo was not seen as or determined to be a major problem for optimization. This is because codes are readily available in existing databases and rule tables could rather easily be constructed. Moreover, new practices in dealing with hazardous cargo are emerging, one such example being the consolidation of all hazardous cargo onto a single pallet.

3FKM3 LOGPLAN Analysis: To aid in the feasibility determination, a LOGPLAN for the UTC 3FKM3 and two supporting UTCs (HFBZP and HFAGC) were obtained to get an indication of the degree to which optimization is typically being achieved under the current manual pallet planning/building. This rudimentary analysis of the 3FKM3, HFBZP, and HFAGC UTCs consisted of determining the number of pallets used and totaling the height (in inches) of all pallets listed in the LOGPLAN. Then the total height was divided by 96 inches (the maximum height allowed for a 463L pallet). Weight was assumed not to be a controlling factor, since the average pallet weight was well

below the 7500 pound allowed maximum. The result of the division (the optimized number of pallets) was then subtracted from the original number of pallets listed in the LOGPLAN to determine the maximum number of pallets that could be saved by optimizing. Although this method ignores hazardous cargo impacts and unusual shape problems, it was accepted as a reasonable approach for obtaining initial estimates of savings by personnel contacted to verify various aspects of this analysis. The analysis indicated a savings of nearly 13 pallet equivalents or approximately one C-141 equivalent, an approximately 20 percent decrease. When this result was presented to unit augmentees, planners, and MAJCOM functional experts, they were not surprised and felt that the results were typical based on their experiences. In one instance, the unit deployment representative estimated the findings within five percent (25%) before hearing of the team's results.

REVIEW AND ANALYSIS OF AUTOMATED METHODS, FINDINGS

Existing Major Systems: Four systems were examined for this study: Automated Air Load Planning System (AALPS), Airlift Loading Model (ALM); Dynamic Analysis and Replanning Tool (DART); and Marine Air Ground Task Force War Planning System II (MAGTF II). Capabilities and intended uses of these systems are summarized in the following paragraphs. The section on Analysis and Discussion considers their applicability to the UTC optimization problem. Two additional systems were investigated during the early stages of this effort: the TPFDD Sizing, Sourcing and Analysis System (TSSAS) and the Optimization Software System of McDonnell Douglas Corporation. No information about these systems could be obtained either from Government sources or the open literature. In the case of TSSAS, it is possible that the information has not yet entered the Defense Logistics Studies Information Exchange (DLSIE) cataloging system.

Automated Air Load Planning System (AALPS): AALPS provides the Army with a standardized, deployable automated air load planning and execution tool for all USAF and CRAF aircraft with the inherent capability of accommodating all air delivery modes. AALPS capabilities support the planning and execution of unit air movements, facilitate the rapid determination of aircraft requirements to support a deploying force, and produce valid load plans and air movement documentation based on planned or actual source data. AALPS will plan and execute air loads in real time by employing artificial intelligence to reproduce the heuristic methods commonly used by expert load planners.

Specific functions of the system include automatic generation of valid aircraft load plans and interactive facilities for user generation of load plans, as well as modification of previously-generated load plans. AALPS applies checks to ensure feasible loads, including two-dimensional and three-dimensional spatial clearance checks, axle weight and overall weight checks, aircraft, equipment, and mission-specific constraints such as cross-loading and center-of-balance constraints. Load plans may be configured for strategic or tactical air-land delivery, air-drop delivery or low-altitude parachute extraction system delivery. Reports produced by AALPS include type-load summary report, summary of type-loads for the aircraft, type-load display for the aircraft type-load, and manifest for the aircraft loadout.

Airlift Loading Model (ALM): The ALM, developed for the Air Force Center for Studies and Analyses, is designed to simulate the loading of military and civilian aircraft to determine the number of sorties needed to deploy a force of any size, and conversely, to determine how much of a particular force can be loaded with a specified number of aircraft. A secondary function of the model is to aid the planner in the sizing of replacement cargo aircraft. The model simulates the loading of aircraft with military equipment consisting of vehicles, troops, and palletized cargo.

Any level of military unit, such as a company or brigade, can be defined in ALM as the building block for determining the deployment order of the forces to be moved. When the movement order of the force to be deployed is defined, vehicle loading begins. Selection of the vehicles to be loaded is based on one of several loading algorithms that the user can select before the simulation begins. The fill-gap loading algorithm is based on loading the widest vehicle out of the total group that fits the gap to be loaded. The top-down loading algorithm loads cargo based on a user-specified sorting sequence for the cargo items. Unlike the fill-gap algorithm, which finds a gap and then looks for a cargo item, this algorithm selects the item and looks for a gap. The floor utilization loading algorithm allows the user to specify a floor-space-to-allowable cabin load (ACL) ratio.

Reports produced by ALM include aircraft load, aircraft load summary, weight distribution, cargo category summary, overall load summary, unit group shortfall, unit group summary, vehicle loadability, aircraft characteristics, and vehicle characteristics.

Dynamic Analysis and Replanning Tool (DART): DART was developed for the Advanced Research Projects Agency (ARPA) and the U.S. Transportation Command (USTRANSCOM). DART is an information management system that enables military planners and operators to edit, analyze, and retrieve transactions from TPFDD files. DART uses a GUI to allow users to build, edit, and modify TPFDD, support transportation feasibility analyses, produce reports and support Course of Action (COA)

selection. The transportation feasibility analyses determine whether or not the ships and planes allocated to carry out the plan are sufficient to deliver all personnel and materiel according to the schedule outlined in the plan.

DART allows planners to modify TPFDD and to set up and run strategic transportation models in a period of minutes rather than the hours or days required using other methods. This makes it possible for planners to consider more alternatives than previously considered and to produce, in less time, a potentially feasible course of action. To support this analytical capability, DART uses modeling tools such as the Rapid Intertheater Deployment Simulator, the Prototype Feasibility Estimator, and the Transportation Feasibility Estimator.

DART is a client/server application. The client software runs on Unix workstations using the X Windows GUI, a relational database, and an open systems architecture. The modeling applications are executed on a Sunserver 1000 server. After completion of the development effort, DART was transitioned to the Defense Information Systems Agency as the executive agent.

Marine Air Ground Task Force Warplanning System II (MAGTF II): MAGTF II provides Marine Corps planners with an automated planning tool that enhances the Joint Operation Planning and Execution System (JOPES) process. It accelerates the capability to develop and source forces of the TPFDD system. MAGTF II is designed to improve and condense the operational planning process through interactive design and database management technologies. It is intended to be used for deliberate and crisis-action planning, as well as for exercise support. Using MAGTF II, planners can develop force structures, tailor force lists, compute sustainment, estimate plan lift requirements, and generate TPFDDs.

MAGTF II aids the planner in refining the force structure, tailoring details, and analyzing the TPFDD through initial development and transfer from JOPES or an existing MAGTF II plan. The results of planning can be transferred to external Marine Corps systems or exported to the MAGTF Deployment Support System II. At any point in the planning cycle, the system can generate files for uploading to the Worldwide Military Command and Control System (WWMCCS) host computer. It will convert a MAGTF II TPFDD into a standard JOPES TPFDD.

The deployment planning functions in MAGTF II provide the planner with the capability to rapidly estimate the number and types of transport aircraft required to airlift a force. Standard lift capacities of Air Mobility Command (AMC) transport aircraft are included in a reference library within MAGTF II. Aircraft not in the reference library may be added as needed. The additions may be made to

plan specific aircraft references that are applicable only to the plan or may be included in the aircraft file in the reference section and thus available to all plans.

The following actions are available in the Airlift Estimation node of MAGTF II: estimate the number of specified types of aircraft required to airlift a force contained within a selected force module (sorties not pre-assigned); determine airlift shortfalls or excesses (sorties pre-assigned); given a set number of aircraft of specific types modify the lift capacity of aircraft to be used in the lift estimations; vary the airlift capacities to be used between wartime and peacetime rates; add or delete aircraft from the plan aircraft reference file; and access the Force Module Summary Screen to determine, create or update force modules from which to do airlift estimates.

OPTIMIZATION AND RELATED MODELS

An Automated Assistant for pallet loading can optimally plan loading a UTC onto pallets if a mathematical or heuristic technique exists and can be applied, given the complexity and constraints of the problem. Even if such a technique can be applied, the technique must be capable of producing a solution within a reasonable amount of time. This is particularly important when replanning must be done in a very time-constrained environment. It must also be considered that the techniques employed may not produce a truly optimal solution. Mathematical techniques for which solution methods are available may be too difficult to fit to the “pallet packing” problem because of the many irregularities and variables such as center of gravity (COG) and hazardous material handling that must be dealt with. A heuristic may be a better fit, but is likely to produce a “near optimal” solution.

Models have been built in the operations research community for many years to simulate packing and loading problems. This type of problem falls under the general heading of “cutting stock” problems. The original focus in this area was to look for ways to cut wood, fabric, or other materials into pieces of different sizes and shapes, while minimizing the amount of material wasted. Conceptually, packing and loading problems are very similar to this original problem.

Much of the research done on cutting stock problems has been theoretical, but for UTC optimization purposes, the focus of this study is on the applied work. Some applied research is concerned with true “cutting” problems for materials. Although cutting stock is not the UTC optimization problem, cutting problems are essentially equivalent to packing problems in two dimensions (i.e., a single layer on a pallet). Other applied research that directly addresses problems of packing and loading containers is reviewed in the following section.

Literature Review: George and Robinson addressed the packing problem in 1980, with their article “A Heuristic for Packing Boxes into a Container.” Their approach used a heuristic that “packed” one layer at a time while trying to maintain an even workface on the layer being filled. The approach is three dimensional and the heuristic chooses the best position and orientation for each box. The model’s choice of orientation could be problematic if there are items that must be loaded “this end up.”

Gehring, Menschner and Meyer also dealt with the three dimensional packing problem in their 1990 article “A Computer-based Heuristic for Packing Pooled Shipment Containers.” Their approach seeks to minimize the wasted space in the container being loaded. The model produces multiple stowage plans, each representing a sub-optimal solution. The user may choose from these plans based on other knowledge about the desirability of the alternatives. The heuristic does allow boxes to be stacked and can handle requirements for weight balancing. However, in its present form, it cannot deal with user-imposed proximity constraints.

Ivancic, Mathur and Mohanty provide a multidimensional knapsack formulation of the packing problem in their 1989 article, “An Integer Programming Based Heuristic Approach to the Three-dimensional Packing Problem.” This model determines positions and orientations of boxes and can handle boxes and containers of various sizes.

Some researchers make a distinction between “manufacturers” packing problems and “distributors” packing problems, where manufacturers consider situations where the boxes are of uniform size and distributors relax this requirement. Dowsland covered the manufacturers pallet loading problem in a 1987 article, “An Exact Algorithm for the Pallet Loading Problem,” which proposes a graph-theoretical model using an exact tree search algorithm for finding solutions. Dowsland’s work is continued in “Efficient Automated Pallet Loading.” This article describes an approach for packing multiple layers on a pallet and considers a second objective (minimizing the number of movements of a robot arm that loads and unloads pallets) in addition to the objective of efficient space utilization.

Another approach to the manufacturers problem is given by Han, Knott and Egbelu in “A Heuristic Approach to the Three-dimensional Cargo-loading Problem.” Their model uses a dynamic programming technique to find the most efficient loading of cargo into a vehicle or container. Their method loads small, uniform prisms (boxes) into a larger prism (a container) by first packing the base and one vertical face, resulting in the packing of an L-shaped region. The algorithm then packs another smaller, L-shaped region and continues in this way until the container is completely packed.

An interesting solution to the distributors problem is given by Chen, Sarin and Ram in their 1991 article, “The Pallet Packing Problem for Non-uniform Box Sizes.” They provide a mathematical model

that optimally places boxes on multiple pallets, minimizing the number of pallets used. It models the orientation of the boxes but only considers the packing of a single layer on each pallet. The solution employs a mixed integer linear programming (MILP) technique to determine which pallet each box is to be placed on, and its orientation and position on the pallet.

Cochard and Yost described a system for building load plans in their 1985 article, "Improving Utilization of Air Force Cargo Aircraft." Their system, called the Deployable Mobility Execution System, employs a modified cutting stock heuristic to generate feasible cargo loads, and then allows users to modify the plans with interactive graphics capabilities. The system was used during the Grenada rescue operation in 1983, where it achieved significant savings in load-planning manhours and improved aircraft utilization.

Other research of tangential relevance to the present problem includes Larsen and Mikkelsen's work "An Interactive System for the Loading of Cargo Aircraft" in the late 70's on minimizing the rearranging of cargo during stopovers; Tsai, Malstrom, and Meeks' model "A Two-dimensional Palletizing Procedure for Warehouse Loading Operations" which requires that all boxes be the same height; Hall's paper "Vehicle Packing" on evaluating tradeoffs between numbers of loads and route length per load; and Bisschoff and Marriott's work "A Comparative Evaluation of Heuristics for Container Loading" that looks at combining heuristics that may be applied to the container loading problem.

ANALYSIS AND DISCUSSION

Existing Major Systems: The current DoD cargo aircraft related automated planning systems, AALPS, ALM, DART, and MAGTF II, offer many sophisticated capabilities to improve the speed and accuracy of deployment planning. However, none of them specifically addresses the loading of 463L pallets, either optimally or otherwise, although some do provide capabilities for creating and modifying aircraft loading plans.

AALPS automates load planning for Air Force and CRAF aircraft, ensuring that planned loads are feasible for the aircraft available. AALPS also can handle various types of cargo delivery. AALPS is not an optimizing system though, and does not deal with the packing of boxes and other items onto 463L pallets. ALM is a simulation model that determines sequences for loading vehicles and cargo onto aircraft and estimates lift requirements. Like AALPS, it does not optimize and does not load pallets. DART helps planners develop and analyze war plans for deploying large numbers of troops and

equipment. It is designed to estimate the feasibility of different courses of action for transporting people and materiel, but does not offer features for dealing with pallets and their contents. The main purpose of MAGTF II is the development and sourcing of force structures. MAGTF II has capabilities for estimating lift requirements, but has no provision for load planning.

The bottom line in this assessment is that these systems do not have sufficient capabilities to be applied to the problem of optimally loading 463L pallets. The assessments and estimates produced by these systems are based on more highly aggregated data than is needed for UTC optimization. Furthermore, the simulation and estimation models employed in these systems are inadequate for combinatorial problems like pallet loading.

Optimization and Related Models: The evaluation of the available operations research models shows that while many research efforts have successfully addressed aspects of the optimal pallet loading problem, none have entirely solved the problem. Thus, we have many partial solutions, but no perfect fit for UTC 463L pallet optimization. Before we discuss the relative merits of the models reviewed, it would be beneficial to present the requirements that a modeling solution must satisfy: multiple layers must be packed on a single pallet; multiple pallets must be accommodated; multiple UTC functions may be packed on a single pallet; total weight constraints must be modeled; center of gravity must be modeled; oversized cargo must be modeled; proximity constraints must be incorporated for hazardous cargo, and “this-end-up” and placement constraints must be handled for fragile items.

Examination of the models in the open literature indicates that nearly all of the important issues for UTC optimization have been addressed, but not by any one research team. George and Robinson provide a solution for packing multiple layers on a pallet (a three-dimensional solution), but their solution does not satisfy many of the other requirements. Gehring et al., also offer a 3D solution that can handle weight balancing, but cannot model the placement of hazardous cargo. Ivancic et al., also provide a useful solution for packing multiple layers when items are not of uniform size and shape. Chen’s team has developed a model that minimizes the number of pallets used to pack a given list of cargo, but only considers one layer at a time in its formulation. Other teams have achieved solutions which would partially satisfy UTC requirements, but again, none are totally satisfactory.

The approach that is most likely to lead to a suitable model for pallet optimization is to select from the existing models the one that appears to offer the best fit as a starting point. This model would then be enhanced, incorporating the features of some of the other models that partially satisfy UTC requirements. For example, the work of the Ivancic or Chen teams might be chosen as the baseline. Their heuristic would be combined with others to achieve a workable model for multi-pallet, multi-layer

packing that minimizes the number of pallets used for a given load. Of course, combining the features of the different models will require the specialized expertise of an operations research professional with knowledge and experience in the theory and applications of “cutting stock” problems. It should be noted that this approach will not necessarily lead to a truly optimal solution for automated pallet packing. Solutions generated by heuristic techniques are frequently “sub-optimal,” but nevertheless are worth implementing because they can provide substantive gains in the desired performance measures such as efficient space utilization or time to completion.

Feasibility Determination: It appears from the research performed on the palletization process and the computer-based techniques available that building and implementing an Automated Assistant is a technically feasible undertaking. Moreover, it also appears to be feasible from a practical point of view as well as technical: the research has shown that there are points in the packing process where technology insertion would lead to significant benefits.

With respect to technical feasibility, a number of issues must be addressed and resolved before an Automated Assistant could be implemented on a large scale. These issues involve the goodness of fit of a chosen solution method, the degree of automation and interaction between the planner and the software, and the display and communication of model results. When speaking of goodness of fit of a model to the packing problem, what is meant is that the model must fit sufficiently well to produce usable results with substantial benefits. This does not imply a 100% fit, however. It may be that in the initial stages of development, some aspects of the packing problem will not be handled. For example, large, irregularly-shaped items might be outside of the scope of the model in the first implementation.

Questions of automation and user interaction are concerned with how much the computer decides versus how much the computer helps the planner decide. For example, the computer-based model might produce a “first cut” packing plan, which the planner may then adjust. Another approach would have the model generate multiple solutions with the planner choosing the “best” one based on subjective information and judgments.

Concerns about the display and communication of model results must be adequately addressed if a truly usable system is to be developed. The optimal packing plan produced by a model will have no value if detailed instructions for loading cannot be generated by the model and provided to the packers. This may necessitate the linking of a model to a graphical interface, like a Computer-Aided Design (CAD) package that will provide the necessary illustrations of how pallet loading should proceed. It will also have to be determined if computer display screens will be appropriate or if paper instructions with diagrams will have to be supplied as well.

True optimization of pallet loading may be possible only if there is a mathematical technique that can be applied and the technique is one for which optimal solution generation methods exist. However, heuristic methods must be considered in lieu of a true optimal solution. The near-optimal solutions that can be generated by heuristics should lead to the desired outcomes, specifically, reduced mobility footprint and greater speed with a reduced need to repack less than optimally packed pallet loads.

CONCLUSIONS

Expert Opinion: There seems to be a consensus within the contingency planning community that there is considerable room for improvement in the way 463L pallets are packed. It is widely acknowledged that space on the pallets is not always optimized and that packing processes are not as effective as they could be. The functional experts also indicate that an automated system would be welcome and would provide much needed support to a task that can be very time and manpower intensive.

Current Systems: As indicated in previous sections, no complete solution currently exists for the pallet packing problem. Systems that aid deployment planners are available in the several Services, but they do not address loading items onto pallets and do not appear to be readily adaptable to such a function.

Feasibility: Although the discussion of feasibility shows that there is no ready-to-use method, it appears that models do exist that could be tailored to the UTC optimization problem. This means that further research is required to produce a model that will adequately capture the goals and constraints of packing 463L pallets while taking advantage of work already accomplished.

Payoff: As discussed previously, optimality in the strict mathematical sense may not be achievable, but the techniques that can be applied will have a significant payoff on key measures. With the implementation of an Automated Assistant, the space available on 463L pallets can be substantially increased. For instance, the expectation is that the number of pallets used on average to transport the analyzed 3FKM3, 18 PAA F-16 UTC could be reduced by nearly 20%. In addition, it is expected that less time will need to be spent building or rebuilding pallets because the Automated Assistant will generate quality loading plans much faster than those created by the manual methods currently in general use.

Further Research: The key area that should be addressed is the development of a suitable modeling technique for “optimized” pallet loading. As previously seen, a number of solutions are partially acceptable and usable as a starting point. Research should continue to produce a technique that adequately models the problem and can generate solutions in reasonable amounts of time. Follow-on research should also continue to investigate methods for displaying the results of the model. It may be necessary to produce loading diagrams “on-the-fly” to give to packers so that the computer generated loading plan can actually be used. Research should also consider appropriate methods of change management. When technology is inserted into an existing process, it should be done in a way that will make it acceptable to users and not viewed as another bottleneck in an already time-critical process. Finally, it would be beneficial to conduct further research into some additional process details, such as the specific rules for loading hazardous cargo, the implications of pallets being loaded on ramp positions in aircraft, and any considerations that may arise when multiple destinations are required for deploying units.

SECTION 2, 463L PALLET LOAD PLANNING OPTIMIZATION CONCEPT

INTRODUCTION

As was discussed in Section 1, the Load Planning Automation Study, there is currently no DoD system that can satisfy the requirements for a UTC Automated Assistant. In fact, none of the systems examined in that section specifically address the loading of materiel onto pallets. Furthermore, none of the DoD systems are sufficiently close enough to the UTC optimization requirement that it would be cost effective to enhance it.

Therefore, a new system must be developed that will offer the capabilities necessary to rapidly build up pallets in the most efficient way possible. In this section, we are not laying out a blueprint for such a system. Rather, we are providing one possible concept of what a system would be like and how it would make optimal pallet loading decisions. This section presents an overview of the concept by addressing three key areas: the functions that a system must provide, the optimization modeling technique that must be implemented, and the means of displaying the model's decisions to the users of the system.

System Functions: A high-level view of the requirements of an Automated Assistant for pallet building shows six principal functional areas: (1) getting the data into the system - importing logistics detail from LOGMOD-B; (2) providing reference information - cargo aircraft specifications; (3) user review and modification - ensuring data completeness and indicating special requirements; (4) finding the optimal solution - executing the appropriate modeling technique; (5) presenting results - screen views and printed reports to guide the build-up activities; and (6) providing "what-if" capabilities - to see the impact of changes in policy or operational methods.

Model/Solution Technique Implementation: An existing pallet building optimization model was chosen to illustrate how such a model would be an integral part of an Automated Assistant for pallet building. Although the model we have selected as an example does not have all of the capabilities required for UTC optimization, it is, nevertheless, an appropriate formulation to demonstrate the concept. The intent is to show some of the key aspects of such a formulation and how they capture the essential elements of the pallet building problem.

The example chosen to illustrate the concept is a model developed by C.S. Chen, S. Sarin, and B. Ram and described in their paper, "The Pallet Packing Problem for Non-uniform Box Sizes." The goal of their model is to optimally place a given set of non-uniform size boxes on a minimum number of pallets. Their model is, therefore, an appropriate approximation of the UTC optimization problem, although it does not have all of the capabilities that the UTC solution requires. A model must be developed in the future to handle all aspects of pallet optimization. This future model could possibly use Chen's model as a starting point. Chen's model is a mathematical programming formulation comprised of the following elements common to this type of formulation:

Decision variables: For each item (box, in their terminology) the model must decide which pallet the item is assigned to, the position on that pallet where the item's southwest corner is placed, and the item's orientation in that position (length or width aligned with the pallet's longer side).

Constraints: There are several types of constraints. One type ensures that every item goes on one and only one pallet. A second type ensures that boxes on the same pallet do not overlap. A third type makes sure that all of the items placed on a pallet fit within the physical dimensions of the pallet.

Objective Function: Mathematical formula that sums the number of pallets as they are assigned to be used. Chen's formulation seeks to minimize this number.

Chen's structure is that of a linear mixed integer mathematical program. It is a linear model because the constraints are all linear equations or inequalities. It is considered mixed integer because some of the variables can take on any numerical value while others can only take on integer values. Once the model has been constructed in computer readable format, it is submitted to a mathematical programming solution package that solves for the values of the decision variables (pallet, position, orientation) subject to the series of constraints in such a way that the objective function (number of pallets used) is minimized.

Display Techniques: A key area of concern in defining the concept for an Automated Assistant is finding the appropriate means of conveying the optimal solution to the individuals who must actually build up the pallets. This is an area that, like the optimization technique, requires additional research. In the concept demonstration that follows, we have employed fairly simple graphics that illustrate how items can be placed onto pallets in accordance with the solution determined by the optimization algorithms. These graphics are intended to be used in conjunction with printed listings that identify each

item and its location on its assigned pallet. When an actual Automated Assistant is built in the future, it may be appropriate to employ CAD technology which would give users the ability to rotate and examine pallet diagrams from different points of view and explode them into layers or vertical slices. This type of technology could allow users to graphically rearrange the items on a pallet using drag and drop method and then see the impact on pallet utilization measures.

PLANNING PROCESS TECHNOLOGY INSERTION

This section provides a detailed discussion of the steps that users would follow when using the Automated Assistant to help determine the optimal way to build 463L pallets. This discussion uses the screens from the Pallet Optimization Toolkit software (see Figure 4) that was developed as part of this effort. These screens will help illustrate how the technology fits into and enhances the process of building up pallets.



Figure 4 - Demonstration Software Front Screen

The Pallet Optimization Toolkit demonstration is stand-alone software that was designed to be used in conjunction with this report to convey the look and feel of an Automated Assistant for building optimized pallets. Because Microsoft Windows is the predominant user interface in current use, the demonstration software was created in that environment. Figures 5, 6, and 7 show how standard Windows-type menus could be used within the Automated Assistant to carry out File, Edit and Tools functions.

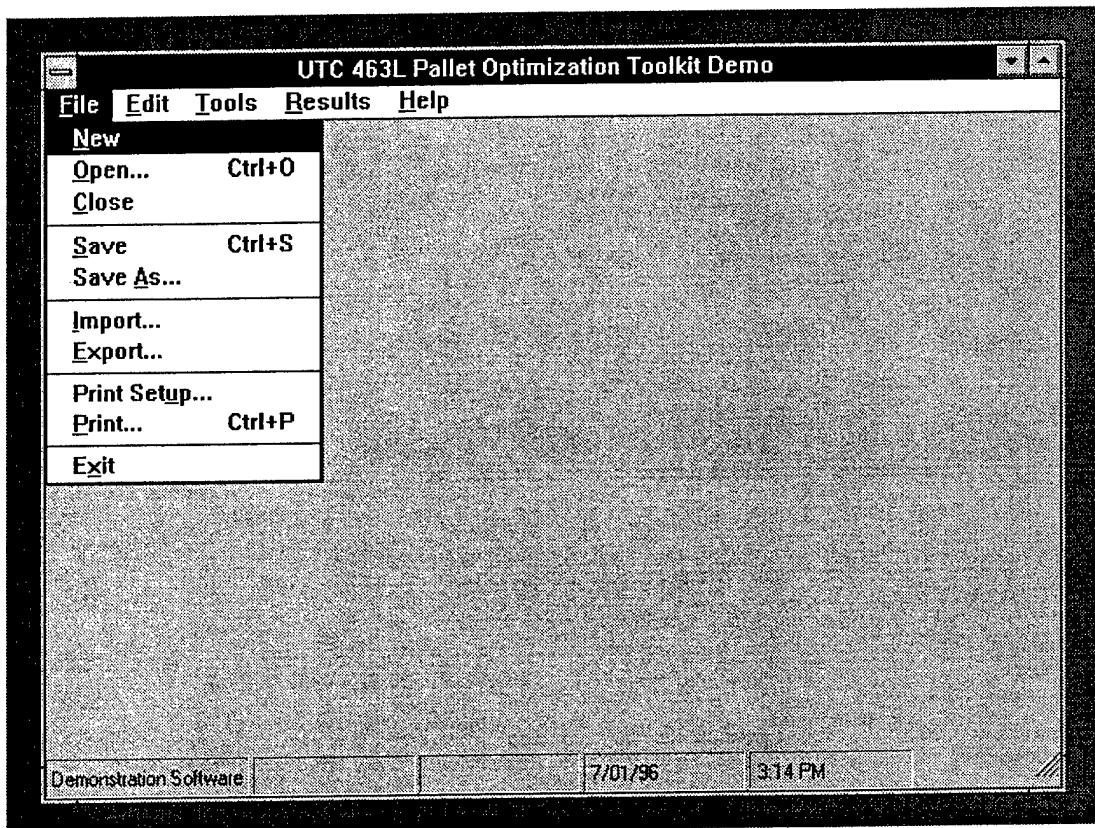


Figure 5 - Windows File Menu

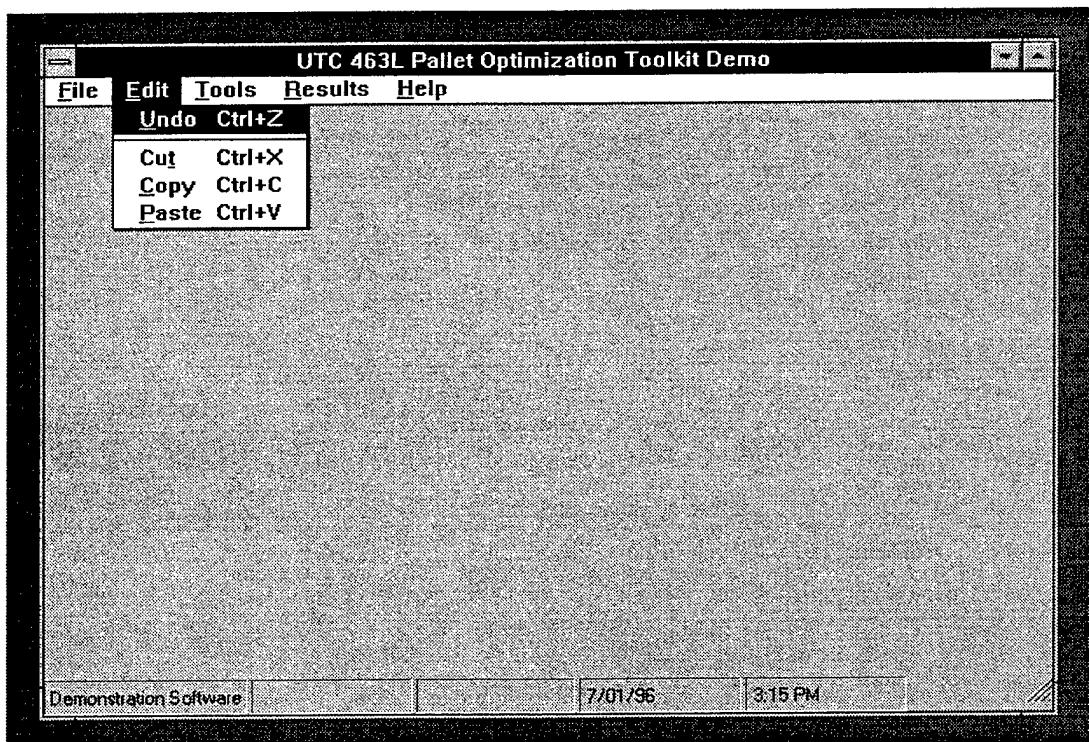


Figure 6 - Windows Edit Menu

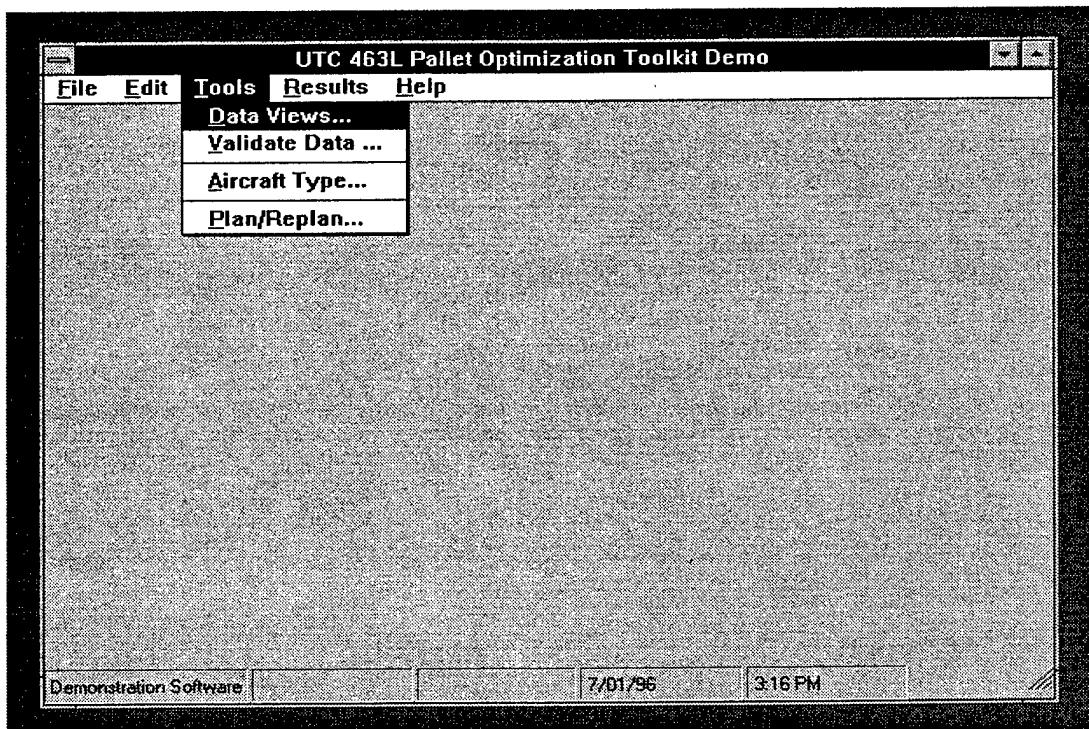


Figure 7- Windows Tools Menu

A useful framework for this discussion of technology insertion is an Input-Process-Output (IPO) view of the task and how the software can support it. Figure 8 shows an IPO chart for the use of the UTC pallet optimizing software.

Input	Process	Output
Load LOGDET	Data completeness check	Building lists
Review LOGDET	Physical limits check	Pallet contents listings
Specify aircraft type	Item exclusion	Packing diagrams
Building/rebuilding selection	Create model input	Exception/exclusion listings
Height/weight restrictions	Execute model	Summary reports
Special requirements	Generate output tables	Comparison reports

Figure 8 - Pallet Optimizing IPO Chart

The remainder of this section is organized according to the IPO view. First, input functions of an Automated Assistant are addressed, followed by the process that must be followed to produce the optimized pallet building lists. Finally, the output products that would need to be generated are covered. Sample screens are shown throughout the section, where appropriate, to illustrate a possible way to implement a function. It should be pointed out that there is not a one-to-one correspondence between the functions and the sample screens. Some functions may require more than one screen, while other “behind the scenes” functions are transparent to the user and therefore have no corresponding screens.

Input: The Automated Assistant must make the development of pallet build-up plans as easy as possible for the end users. The input functions of the system must automatically get and make accessible as much of the input data as possible and give users the ability to review and correct the data if necessary. Users also need the ability to specify the type of aircraft that will be used and set up any other conditions that are appropriate to the planned deployment.

Loading Logistics Detail: The first input function that the system will perform is pulling in the item data (see Figure 9), the Logistics Force Module (LOGFOR) Wing Materiel List which contains National Stock Number (NSN), weight, cube, and nomenclature from LOGMOD-B via the DeMS and is transparent to the user. In addition to item identification, these lists contain the dimensional information required to determine the optimal pallet build. They are organized by UTC, deployment echelon, and increment number, and this organization will be maintained in the system for the convenience of the users.

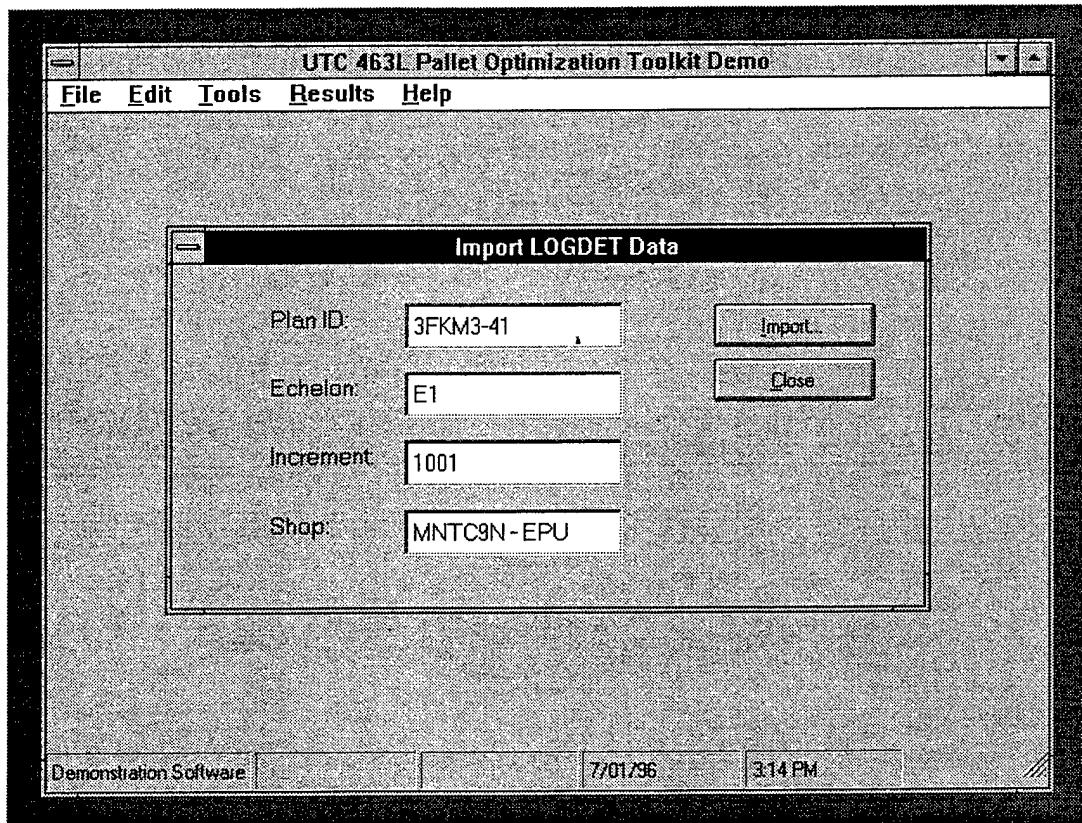


Figure 9 - Importing LOGDET Data

Reviewing Logistics Detail: Users need the capability to review the logistics detail information after it has been loaded into the system (see Figure 10). They need to check for completeness and correctness and make changes whenever the imported information is not appropriate to their situation. This function will also allow the users to mark items to be excluded from the pallet build-up computation if the items are not required for the current deployment or are simply not compatible for palletization with certain cargo mixes.

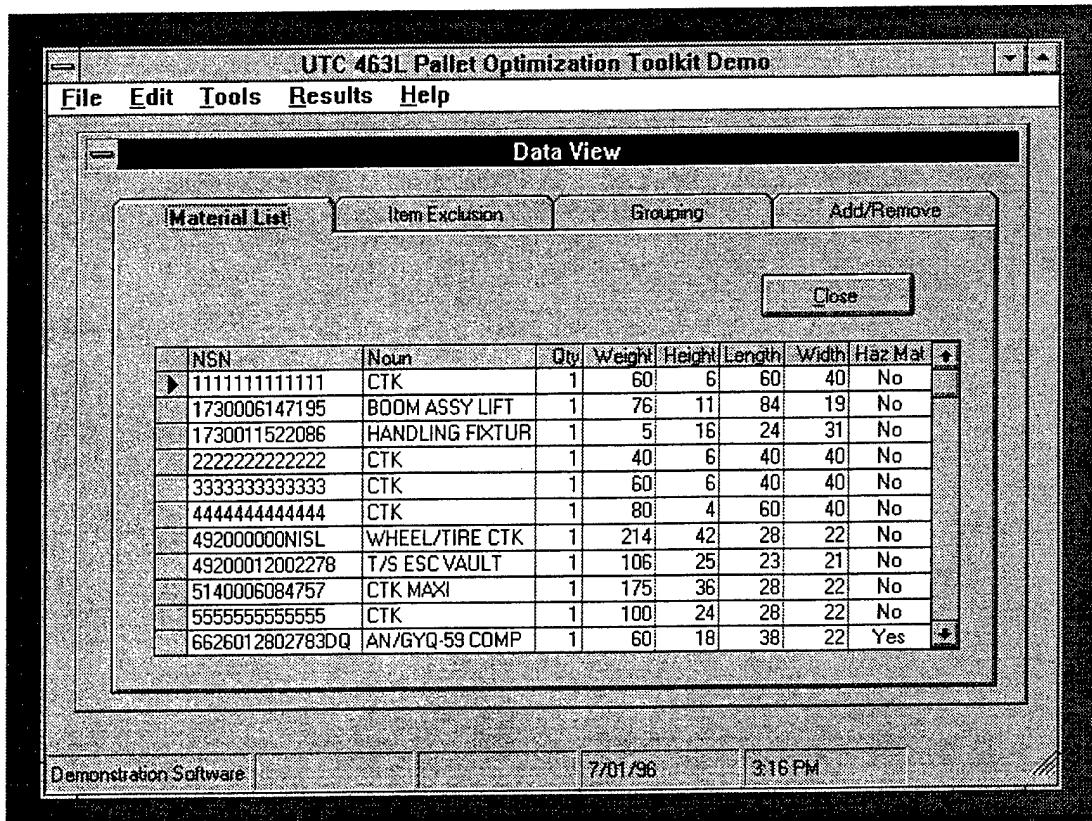


Figure 10 - Reviewing LOGDET Data

Specifying Aircraft Type: One of the key parameters of the pallet optimization process is the type of cargo aircraft being employed to transport the palletized cargo. Specifically, the aircraft type may impose restrictions on the height, length, or width of the pallets that may be loaded onto the aircraft, either in total or in certain positions within the plane. The Automated Assistant will maintain a reference section of cargo aircraft specifications that may be accessed by users at any time. Prior to computing an optimal pallet build-up plan, users will select the type of aircraft from the list in the system (see Figure 11) to be input to the model to constrain maximum pallet height.

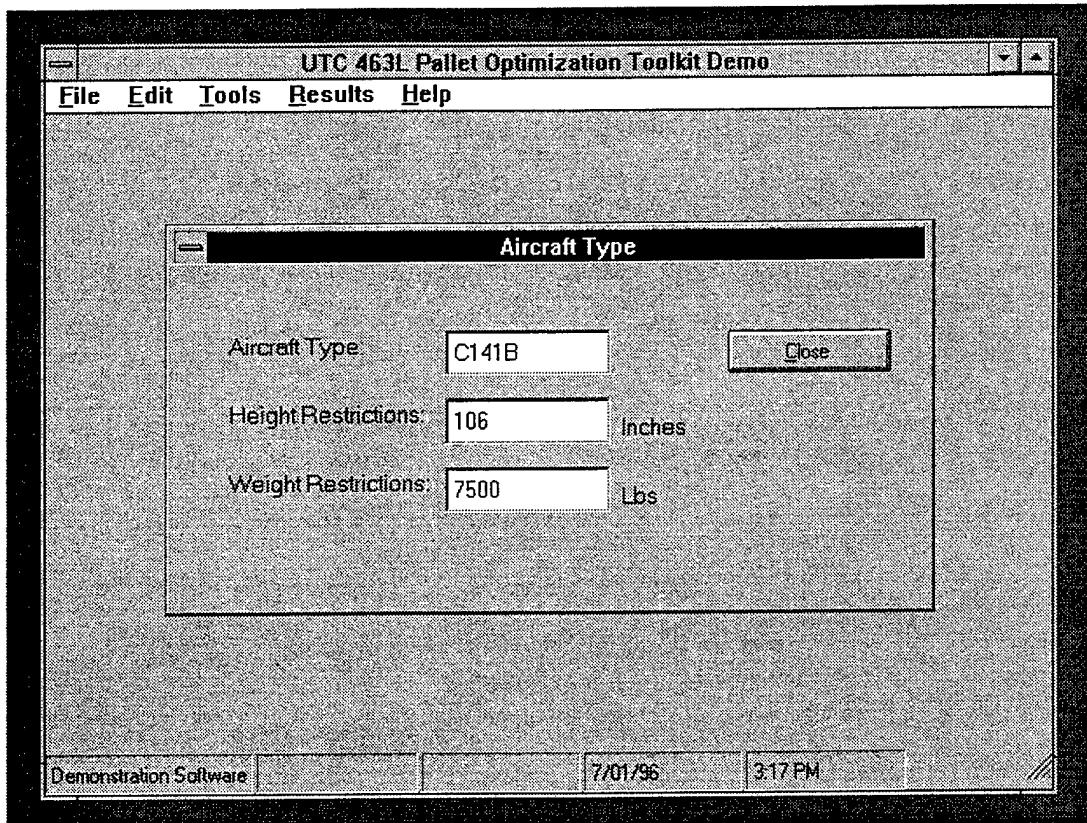


Figure 11 - Choosing Aircraft Type

Building/Rebuilding Selection: Situations may arise where a portion of an increment may need to be reloaded, possibly due to a change in cargo aircraft being used. A change in aircraft may require that pallets be built to a different, lower maximum height, length, or width than was originally planned. This function of the Automated Assistant would allow users to generate a revised building plan for a subset of the pallets for the given increment, leaving the others in their original state (see Figure 12). The system would, in effect, remove pallets and their contents from the re-optimization run and re-accomplish only those pallets that would be subject to the more restrictive constraint. Users would indicate which pallets are to be left out of the re-optimization.

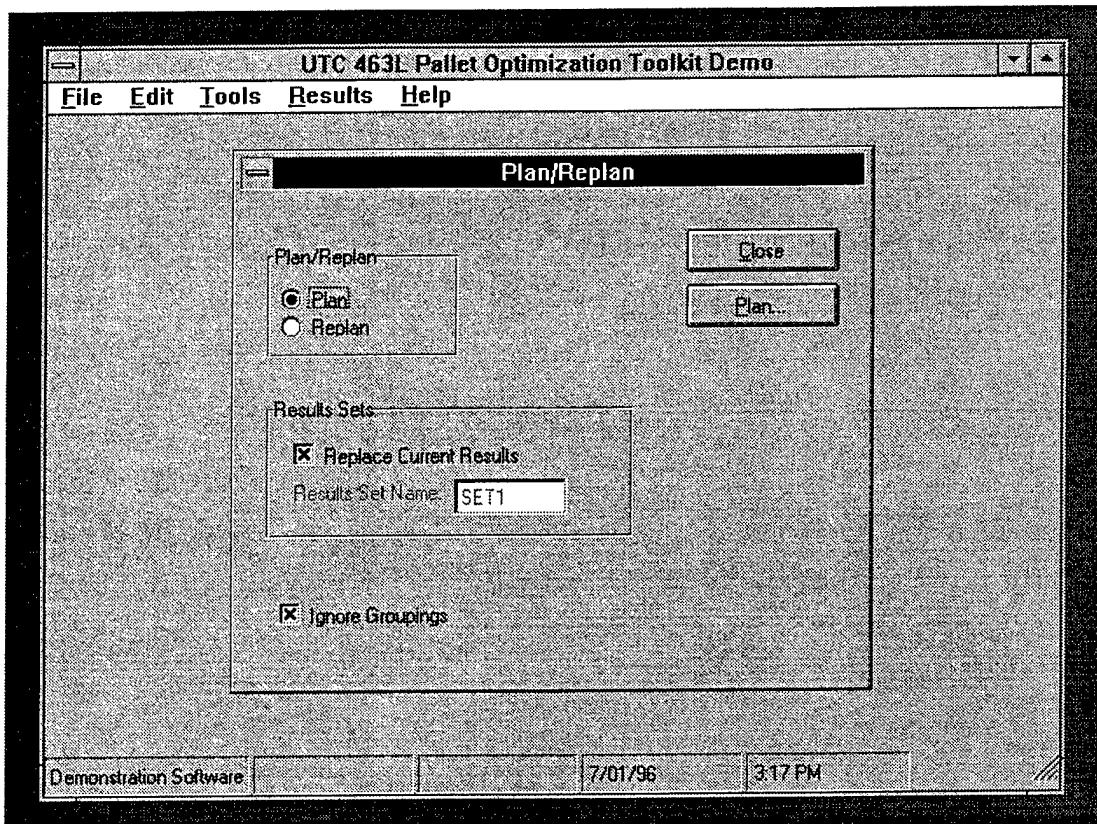


Figure 12 -Planning/Re-Planning

Height/Weight Restrictions: This function would give users the ability to override some of the standard constraints embedded in the system. For example, a decision may be made to relax the 7500 pound weight limit for the 463L pallet and allow pallets to be built up to their designed maximum weight of 10,000 pounds. If the user entered a new pallet weight limit through this function (see Figure 11), the system would incorporate that limit in the model constraints that keep the loaded pallet weight within the set limits.

Special Requirements: This function allows a user to create groupings of items that must be kept together (or loaded onto the same pallet) during pallet build-up. For example, a shop chief may have a set of items that should be loaded on the same pallet. This function would allow the user to set up named item groups and assign individual items to those groups. These groups would then become additional constraints in the model. This function could also be used to implement a policy of putting all hazardous items on a single pallet. In effect, a hazard group would be created, items with the appropriate hazard codes would be assigned to the group, and the system would find locations for all of the items on one pallet.

Process: The process section of the IPO chart shows the steps that must be carried out to prepare the data in the system for the optimization run, to actually carry out the optimization run, and then conduct the post-processing that must occur to make the systems decisions available to the user. Most of what happens in this entire sequence is transparent to the user of the system. The user needs to be involved only when a circumstance arises that requires a corrective action or a decision.

Data Completeness Check: The system must check the data for each item in the logistics detail to ensure that all fields have values required by the optimization model (see Figure 13). For example, if dimensional information were missing for an item, the item could not be included in the optimized loading plan. If an item has one or more missing data elements, this condition must be presented to the user who will be prompted to supply the required information.

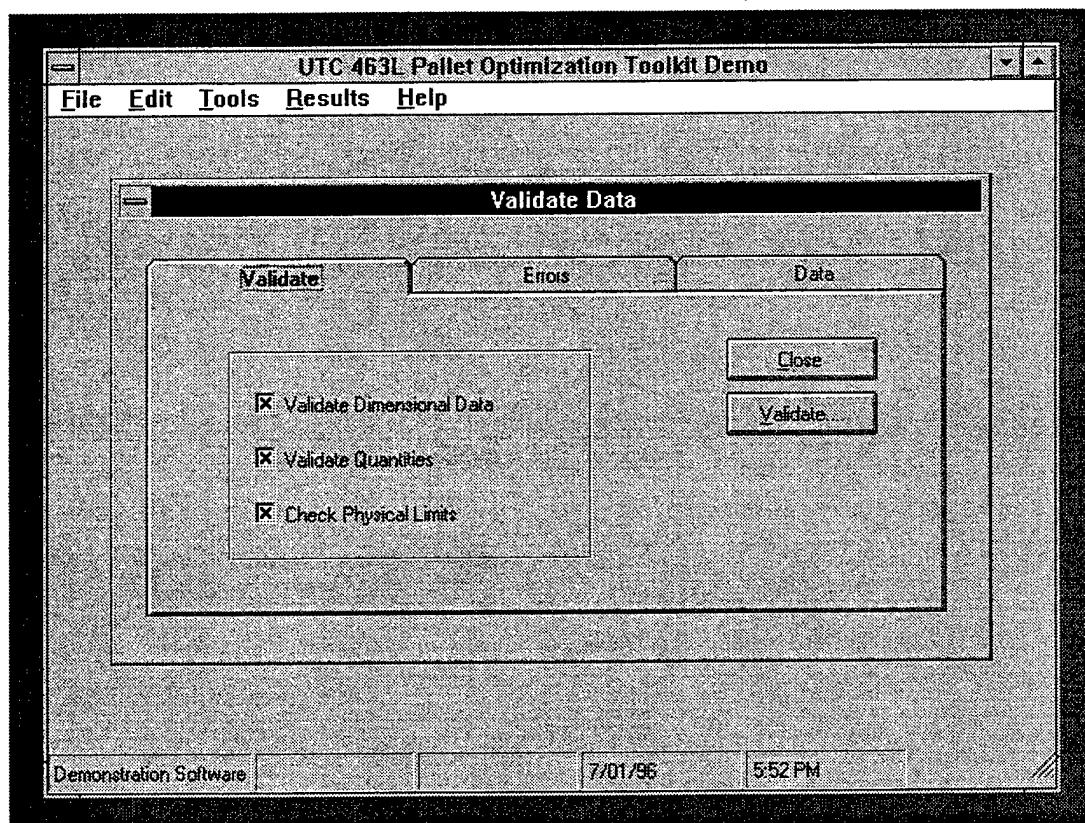


Figure 13 - Validating Data and Checking Limits

Physical limits check: The system must check for any items which have one or more dimension(s) that exceed the maximum allowed (see Figure 13). This might be an item with a height in

excess of either the standard pallet maximum height of 96 inches or the maximum height for the particular cargo aircraft that is being employed. An oversized dimension situation would also occur for an item with a length or width that exceeds the pallet maximum and must accordingly be loaded onto two pallets (married pallets).

In any of these situations, the user will be advised that a maximum dimension has been exceeded and that appropriate action must be taken. If an item exceeds the allowable height, it must be removed from the pallet optimization computation. If an item exceeds the allowable length or width and requires that two pallets be married, the item will be taken out of the optimization, but the two pallets will be allocated and this information will be captured for the optimization summary.

Item Exclusion: In addition to the circumstances just described, there are other situations for which the system must remove items from the optimization computation. If, during review of the logistics detail, the user decides that certain items should not be included, the system must remove them from the computation. The other situation occurs when an optimization has been performed, but some portion of the UTC must be repacked, possibly because of a change in the available cargo aircraft. In this case, many of the pallets that have been optimized will not need to be re-optimized. Therefore, items on those pallets will be taken out of the computation and the re-optimization will be run on a subset of the items originally optimized.

Create Model Input: After all completeness and validity checks have been performed, the system will create the mathematical programming formulation to produce the optimal pallet loading configuration. The formulation, which will be based on the logistics detail, rules for build-up, aircraft type, and user specifications, will include decision variables (the mapping of each item to a specific pallet and position on the pallet); standard constraints (physical dimensions, center of gravity, hazardous materials); user-specified constraints (special height or weight restrictions, item proximity groupings), the objective function (minimize the number of pallets used); and information variables (unused space on each pallet). The system will produce a model of the specific building problem in a format that can be used by a mathematical programming (optimization) solution package. Examples of software of this type are OSL from IBM and Lindo from Lindo Systems.

Execute Model: To produce an optimal solution for a given problem, the system must invoke a mathematical programming package with the properly formatted model as input. The math programming software would apply its solution algorithms and solve the model; that is, it will find values for all of the

decision variables (assign each item to a pallet position) such that the minimum number of pallets is used and all of the specified constraints have stayed within their limits.

Generate Output Tables: The solution as it comes from the optimization package is not directly usable and must be translated into a form that makes sense to the planners and packers. Therefore, the system will generate output tables that will contain the one-to-one mapping of the items to the pallet positions. This will enable the output functions of the system to display the results in various ways that can best facilitate the building up of the pallets.

Output: A variety of output products (see Figure 14) will be produced by the system to effectively convey to the packers the recommendations of the optimization model. The system must show the user where each item is to be loaded as well as the proper sequence for loading. This will be accomplished through the use of listings and diagrams.

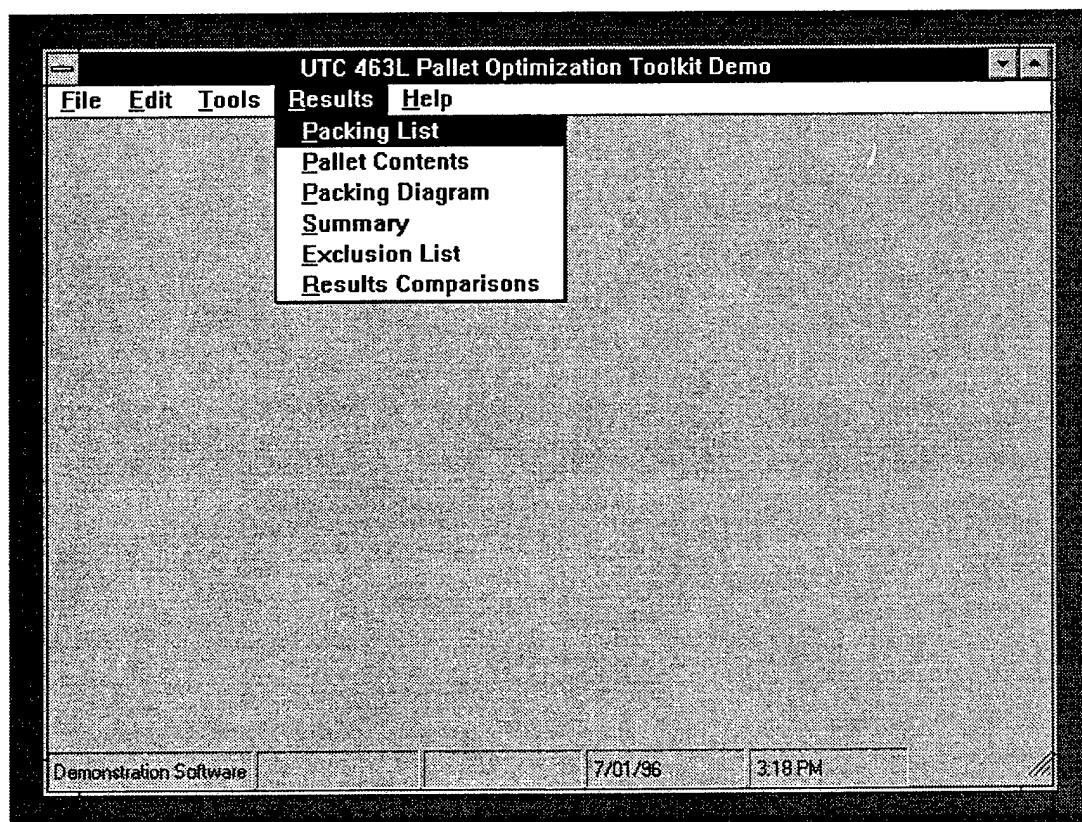


Figure 14 - Selection of Results

Packing Lists and Pallet Contents: The packing lists (Figure 15) and pallet contents (Figure 16) will present to the user the list of items to be packed, along with the pallet number that the item is to be loaded on, the layer on the pallet (numbered from bottom to top), and the position within the layer (sequenced from A to ZZ, row by row). The position code shown includes pallet number, layer, and sequence, for example, 22A. These lists will also identify any special groupings that were considered as well as any special handling information such as hazardous cargo codes. The pallet contents and packing diagrams would be furnished to and used by the pallet builders to direct cargo and equipment placement or to locate a specific item on a pallet already built. The Packing Lists (by NSN) would primarily be used at the deployed site to assist in locating individual items.

Packing List

Plan ID: 3FKM3-41		Echelon: E1	Shop: M		
Aircraft: C141B		Increment: 1001			
<u>NSN</u>	<u>Noun</u>	<u>Pallet ID</u>	<u>Layer</u>	<u>Position</u>	<u>Mul</u>
1111111111111	CTK	2	2	22A	No
1730006147195	BOOM ASSY LIFT	1	1	11G	No
1730011522086	HANDLING FIXTURE	1	3	13E	No
2222222222222	CTK	2	2	22B	No
3333333333333	CTK	2	2	22C	No
4444444444444	CTK	2	2	22D	No

← | → | 1 of 2 | Cancel |  |  |  | Close | 25 of 25 | Total 25 | 100% | + |

Figure 15 - Packing List

Pallet Contents					
Plan ID:	3FKM3-41	Echelon:	E1	Shop:	M
Aircraft:	C141B	Increment:	1001		
Pallet ID	Layer	Position	NSN	Noun	
1	1	11A	723591350SD	BIN METAL WSD	
1	1	11B	492000000NISL	WHEEL/TIRE CTK	
1	1	11C	49200012002278	T/S ESC VAULT	
1	1	11D	7125P1350SD	BIN METAL WSD	
1	1	11E	5140006084757	CTK MAXI	
1	1	11F	701002537419	MLV POWER SUPPLY	
1	1	11G	1730006147195	BOOM ASSY LIFT	
1	1	11H	6626012802783DQ	AN/GYQ-59 COMP	
1	2	12A	55555555555555	CTK	
1	2	12B	66666666666666	CTK	
1	2	12C	77777777777777	CTK	
1	2	12D	88888888888888	CTK	
1	2	12E	99999999999999	CTK	
1	2	12F	AAAAAAAAAAAAAA	CTK	
1	2	12G	BBBBBBBBBBBBBB	CTK	
1	3	13A	7010012537419	DTTU MONITOR	
1	3	13B	7010012537419A	DATA ACCESSORY	

Figure 16 - Pallet Contents

Packing Diagrams: A packing diagram will be generated for each layer on each pallet. It will present a two-dimensional view of a layer on a pallet, with an identifier displayed for each position on the layer. This identifier, which will be a one- or two-letter code (sequenced from A to Z, AA to ZZ), will also be shown on the corresponding packing list. By using the pallet packing diagrams in conjunction with the pallet contents listings, packers will be able to place each item correctly in the position specified by the optimization algorithms. Figure 17 shows a sample packing diagram for pallet building.

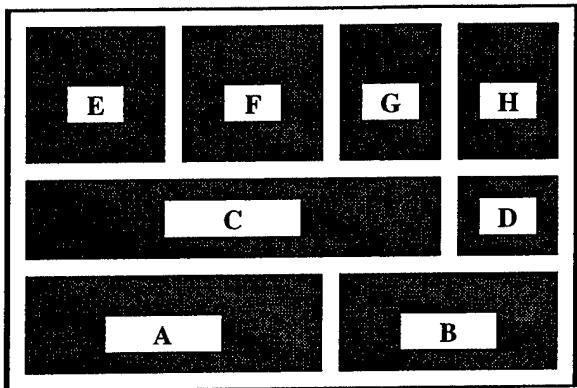


Figure 17- Sample Pallet Building Packing Diagram

Exception and Exclusions Reporting: This list (Figure 18) will present in the original LOGFOR NSN ordering all of the items that were excluded from the current pallet optimization run. This will include items selected by the user to be excluded, items excluded because the optimization is running only for a subset of items to be repacked, and exceptional situations for oversized items. The reason for the exclusion (partial repacking, height exclusion, user selection, oversized item,) will be given for each item.

Exclusion List				
Plan ID: Aircraft:	Echelon: Increment:	Shop:		
NSN	Noun	Include/Exclude	Group Code	Ha

Figure 18 - Exclusion List

Summary Report: This report (Figure 19) will present summary statistics for the pallet optimization run. These statistics include the total number of pallets used, number of married pallet situations, number of special groupings included, and total weight of items packed. Statistics for each pallet (maximum height reached, total weight, number of items, and the presence of special groupings and hazardous cargo) will also be displayed.

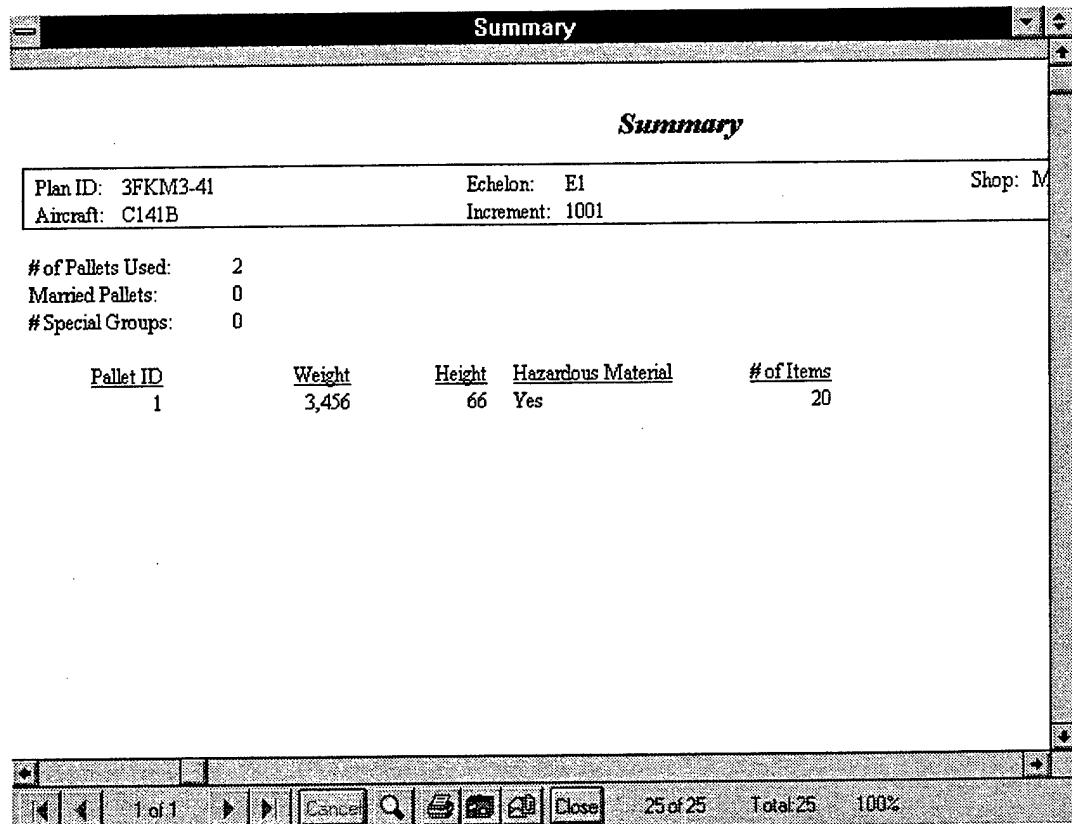


Figure 19 - Summary Report

Comparison Report: This report would only be generated in situations where a user asks the system to perform a “what-if” optimization after a baseline case has been run. For example, a user may want to see the effect on pallet utilization of having all hazardous items loaded on a single pallet. Depending on the bulk of these items as well as the rest of the items, the result could be that an extra pallet is required to accommodate this additional restriction. The comparison report will display summary statistics for the baseline case and the “what-if” case side by side to facilitate comparison.

CONCLUSIONS

One of the major goals of this paper was to define a concept for an automated 463L pallet load planning optimization system. This has been accomplished and documented in this section and the accompanying demonstration screens. We have shown how the software could look, how it could operate, and how an optimization technique could be included to find optimal pallet loading solutions. We have also illustrated how the planning decisions of the model could be conveyed to the users through reports and diagrams.

As the UTC-Optimization effort moves forward to the development and pilot project phase, the area that will require the most concentrated attention is that of developing a suitable optimization model. As previously pointed out, there is no known model that can do everything that must be done to optimally load 463L pallets, although nearly all of the models examined offer some usable capabilities.

The modeling approach developed by Chen, et al., that was selected for the concept demonstration appears to have the most to offer as a baseline that could be enhanced to provide the necessary functionality. Probably its major shortcoming is that it is a two-dimensional model, meaning that it only loads a single layer of items onto each pallet. Its other serious deficiency is the lack of any means of handling weight restrictions. This is important in UTC-Optimization for two reasons: maximum pallet weight cannot be exceeded and heavy items should not be loaded on top of lighter, more fragile items. However, this is not to say that Chen's model is not a good candidate for enhancement.

Of course, Chen's is not the only model that could be used as a starting point for future work. Others that were discussed in the previous optimization report could potentially be used as well. In fact, the best solution may lie in combining two or more existing approaches. Besides the mathematical programming approaches, approaches that use heuristics were also reviewed. Some of these appear to be worthy of future consideration, although the solutions they produce may not be optimal in the strict mathematical sense. Nevertheless, they may produce substantial improvements over current non-automated methods.

A 463L pallet load planning optimization toolkit concept, as presented in this paper, appears to significantly improve the following when compared to the current "manual" process in terms of speed of planning and loading: accuracy of planning and execution; flexibility for replanning; asset visibility by position and layer; and training. All of these factors/areas impact deployment and are obvious contributors to readiness and deployability. Therefore, it is reasonable to conclude that automation of the current process could significantly help improve readiness and the ability of units to deploy their UTCs. Optimization of military resources is no longer desired; it is required. Given today's complex

environment of potential combat operations, as well as operations other than war, every effort should be made to provide the warfighter maximum capabilities from finite resources.

SECTION 3, RECOMMENDATIONS

An Automated Assistant for loading 463L pallets can and should be designed and implemented. The deployment planning personnel contacted acknowledged its potential value. Moreover, the job is feasible from both technical and pragmatic points of view. Additional research should be carried out for the Automated Assistant to become a reality.

The following are the major tasks that should be accomplished: a suitable modeling technique should be developed, possibly as an adaptation of an existing model; display techniques should be investigated for communicating model load plans to packers; changes in management methods should be applied to ensure acceptance and appropriate utilization; and additional and adjunct aspects of the current process such as CRAF aircraft impacts should be studied. Those major systems (TSSAS and the optimization software system of McDonnell Douglas Corporation) on which we were unable to obtain sufficient information for evaluation should be revisited, along with some major commercial cargo carriers. Finally, a comprehensive plan should be developed to implement a pilot project. This should include the development and implementation of an initial operating capability at a single site.

APPENDIX A: TERMS

Building (463L Pallet) - The act of placing or loading and securing cargo on a 463L pallet.

Bulk - Cargo designation for cargo that can be loaded onto a standard 463L airlift cargo pallet.

Cargo Category Codes - Descriptive codes assigned to deploying cargo according to their characteristics and properties. Codes are used for transportation planning.

Civil Reserve Air Fleet (CRAF) - A group of commercial aircraft with crews which is allocated in time of emergency for exclusive use in both international and domestic service.

Contingency - An emergency involving military forces caused by natural disasters, terrorists, subversives, or required military operation.

Contingency Operation and Mobility Planning and Execution System (COMPES) - Air Force standard system that supports the Joint Operation Planning and Execution System (JOPES). It integrates operations, logistics, and manpower processes and data. It was intended to enable planners to develop and access near real-time data from service and joint systems. Air Force planners use the system to translate joint tasking into detailed unit tasking. COMPES defines the manpower and materiel required down to the Air Force Specialty Code (AFSC) and tool box level.

Deliberate Planning - The JOPES process involving the development of joint operation plans for contingencies identified in joint strategic planning documents. Conducted principally in peacetime, deliberate planning is accomplished in prescribed cycles that complement other Department of Defense planning cycles and in accordance with the formally established Joint Strategic Planning System.

Deployment - The relocation of forces to designated areas of operations.

Deployment Echelon - A UTC capability that commanders must deploy as a single entity. Deployment echelons facilitate deployment planning by identifying a unit's capabilities, materiel, and personnel requirements, and designating the sequence of movement.

Desired Maximum Pallet Weight - 7500 lbs. Based on prolonging pallet life.

Emerging System - A system which is being fielded but is not yet at Full Operating Capability (FOC).

Force Package - A predefined standardized grouping of manpower and/or equipment which provides a specific wartime capability. It is not unusual for a force package to be referred to as a UTC or UTC package.

Hazardous Cargo - Explosives and other hazardous articles such as flammable liquids and solids, oxidizing materials, corrosive materials, compressed gases, poisons, irritating materials, etiologic agents, radioactive material, and other unregulated cargo.

Increment of Materiel - Equipment, supplies, and spare parts that units use to plan and assemble loads for deploying cargo aircraft. Units normally design increments to fit a standard 463L pallet, but may combine material that support more than one deployment capability to form an increment if space remains on a pallet.

LOGFOR - A subsystem of both MEFPAK and COMPES. Used to collect and store LOGDET for UTCs. It provides equipment and materiel requirements and summarized transportation characteristics through its LOGDET component.

Local Area Network - A telecommunications system within a specified geographical area that allows a number of independent devices to communicate with each other. These networks can be configured to interchange voice, data, graphics, video, or other forms of electronic messaging.

Legacy Data System - FOC functioning Automated Data Processing (ADP) system.

Manpower and Equipment Force Packaging System (MEFPAK) - The Air Force data system for UTC package management.

Manpower and Equipment Force Packaging System Command - MAJCOM or Field Operating Agency designated by a HQ USAF Functional Area Manager to develop and maintain detailed data for a UTC package for use throughout the Air Force.

Marrying Pallets - Connecting or joining multiple 463L pallets for cargo exceeding the dimensions of a single pallet.

Maximum Cargo Stacking Height (463L Pallet) - 96".

Maximum Pallet Weight - 10,000 lbs.

Maximum Pounds Per Square Inch (463L Pallet) - 250 PSI.

Measurement Ton - Unit for volumetric measurement of equipment associated with cargo. Total cubic feet divided by 40 (1 MTON = 40 cu ft).

Multi-Pallet Train - Two or more 463L pallets joined together, e.g., two-pallet train, etc.

Net Set - Two side nets (HCU-7/E) and one top net (HCU-15/C). Rated capacity = 10,000 lbs. Set weight = 354 lbs., T.O. 35D33-2-3-1.

Operations Other Than War (OOTW) - Military activities during peacetime and conflict that do not necessarily involve armed clashes between organized forces or sustained combat.

Outsized Cargo - Cargo that exceeds 1090" x 117" x 105" (requires a C-5 aircraft for movement).

Oversized Cargo - Cargo that exceeds usable volume of a 463L pallet. Over 104" x 96", or height of the aircraft cargo area..

Pallet - HCU-6/E (NSN: 16700008204896CT), 463L airlift cargo pallet. Size: L 88" x W 108" x H 3", weighing 290 lbs., T.O. 35D33-2-2-2.

Pilot Unit - Unit tasked to develop the standard manpower and/or logistics (Manpower and Force Equipment List and LOGDET) portion of a UTC package for use by all units (non-pilot) with the same functional tasking or the same weapon system.

Redeployment - The transfer of a unit, an individual, or supplies deployed in one area to another area, location within the area, or to the zone of interior.

Short Ton - Unit of cargo measurement for equipment or supplies (STON or S/T = 2,000 lbs).

Throughput - Estimated traffic expressed as an average daily capability of MTONs, STONs, and/or passengers (PAX).

Unit Type Code - A five-character, alphanumeric computer code that uniquely identifies each type unit of the Armed Forces.

Usable Pallet Dimensions - L 84" x W 104" x H 96"

APPENDIX B: ABBREVIATIONS AND ACRONYMS

AALPS	Automated Air Load Planning System
ACL	Allowable Cabin Load
ADP	Automated Data Processing
AFLMA	Air Force Logistics Management Agency
AFSC	Air Force Specialty Code
AL	Armstrong Laboratory
ALM	Airlift Loading Model
AMC	Air Mobility Command
ARPA	Advanced Research Projects Agency
BCAT	Beddown Capability Assessment Tool
CAD	Computer Aided Design
COA	Course Of Action
COG	Center Of Gravity
COMPES	Contingency Operation/Mobility Planning & Execution System
COTS	Commercial Off-the-Shelf
CRAF	Civil Reserve Air Fleet
DART	Dynamic Analysis and Replanning Tool
DeMS	Deployment Management System
DLSIE	Defense Logistics Studies Information Exchange
ECLiPSE	Enhanced Contingency Logistics Planning and Support Environment
EKB	Employment Knowledge Base
FOC	Full Operating Capability
GUI	Graphical User Interface
IDEF	Integrated Definition Modeling
IDS	Integrated Deployment System
IPO	Input-Process-Output
JOPES	Joint Operation Planning and Execution System
LIMFACS	Limiting Factors
LOG-AID	Logistics Analysis to Improve Deployability
LOGCAT	Logistician's Capability Assessment Tool (formerly ECLiPSE)
LOGDET	Logistics Detail

LOGFOR	Logistics Force
LOGPLAN	Logistics Plan
MAGTF II	Marine Air Ground Task Force II
MAJCOM	Major Command
MEFPAK	Manpower and Equipment Force Packaging
MDS	Mission, Design, Series
MILP	Mixed Integer Linear Programming
NOPLAN	No Operation Plan
NSN	National Stock Number
OPLAN	Operation Plan
OSE	Open System Environment
PAA	Primary Authorized Aircraft
R&D	Research and Development
STEP	Survey Tool for Employment Planning (formerly DISE)
TCN	Transportation Control Number
TPFDD	Time Phased Force Deployment Data
TSSAS	TPFDD Sizing, Sourcing, and Analysis System
ULN	Unit Line Number
USTRANSCOM	United States Transportation Command
UTC	Unit Type Code
UTC-DTO	Unit Type Code Development, Tailoring, and Optimization
WWMCCS	WorldWide Command and Control System

APPENDIX C: REFERENCES

Air University, Contingency Wartime Planning Course (CWPC), Course Materials Guide, 14 April 1995.

Bisschoff, E., & Marriott, M. (1990). A Comparative Evaluation of Heuristics for Container Loading. *European Journal of Operational Research* 44(2), 267-276.

Chen, C., Sarin, S. & Ram, B. (1991). The Pallet Packing Problem for Non-uniform Box Sizes. *International Journal of Production Research* 29(10), 1963-1968.

Cochard, Douglas, & Yost, Kirk, (1985). Improving Utilization of Air Force Cargo Aircraft. *Interfaces* 15(1), 53-68.

Cross, LtCol Stephen, & Estrada, Richard (1994). DART: An Example of Accelerated Evolutionary Development. *Proceedings of the Fifth International Workshop on Rapid System Prototyping*.

Chairman of the Joint Chiefs of Staff, CJCS Instruction 5714.01, Release Procedures for Joint Staff and Joint Papers and Information, 29 April 1994.

Defense Logistics Studies Information Exchange (DLSIE), Automated Air Load Planning System, Information Booklet, LD072263MB, June 1987.

Defense Logistics Studies Information Exchange (DLSIE), Airlift Loading Model (ALM); User Manual, LD091489MC, August 1987.

Defense Logistics Studies Information Exchange (DLSIE), Support for the Automated Air Load Planning Systems (AALPS), Final Report, AD-B130095, January 1989.

Department of the Air Force, Communications, Air Force Policy Directive 33-1, Command, Control, Communications, and Computer (C4) Systems, September 1993.

Department of the Air Force, Operations, Air Force Manual 10-401, Operation Plan and Concept Plan Development and Implementation, October 1994.

Department of the Air Force, Operations, Air Force Instruction 10-402, Mobilization Planning, February 1994.

Department of the Air Force, Operations, Air Force Instruction 10-403, Deployment Planning, 10 June 1994.

Department of the Air Force, Operations, Air Force Instruction 10-404, Base Support Planning, 16 November 1994.

Department of the Air Force, Operations, Air Force Instruction 10-408, Mobility for AFMC Support Forces, April 1994. (formerly AFR 76-6)

Department of the Air Force, Operations, Air Force Instruction 10-503, Air Force Base Survey and Unit Beddown Program, July 1995.

Department of the Air Force, Operations, Air Force Pamphlet 10-1401, Airlift Planning Factors, May 1995. (formerly AFR 76-2)

Department of the Air Force, Transportation, Air Force Policy Directive 24-2, Preparation and Movement of Air Force Materiel, April 1993.

Department of the Air Force, Transportation, Air Force Instruction 24-201, Cargo Movement, June 1994.

Department of the Air Force, Transportation, Air Force Joint Manual 24-204, Preparing Hazardous Materiels for Military Air Shipment, November 1994.

Department of the Air Force, Transportation, Air Force Joint Instruction 24-211, V4, Defense Traffic Management Regulation: Transportation Facility Guide, Air Force, November 1994.

Department of the Air Force, Technical Order 1C-5A-9, Loading Instructions Manual, USAF SERIES, C-5A AND C-5B Airplanes, August 1984.

Department of the Air Force, Technical Order 1C-10(K)A-9, Cargo Loading Manual, USAF SERIES, KC-10A Aircraft, Change 7, July 1990.

Department of the Air Force, Technical Order 1C-130E-5, Technical Manual, Basic Weight Checks, Lists, and Loading Data, USAF SERIES, C-130E, C130H, and LC-130H Aircraft, June 1987.

Department of the Air Force, Technical Order 1C-135(K)A-9, Cargo Loading Instructions USAF SERIES, KC-135A, KC-135E, KC-135, February 1995.

Department of the Air Force, Technical Order 1C-141B-9, Manual, Loading Instructions, USAF SERIES, C-141B Aircraft, January 1995.

Department of the Air Force, Technical Order 35D33-2-2-2, 463L Air Cargo Pallets Types HCU-6/E and HCU-12/E, September 1994.

Department of the Air Force, Technical Order 35D33-2-3-1, 463L Air Cargo Nets Types HCU-7/E and HCU-15/C, June 1993.

Department of the Navy, United States Marine Corp, Marine Air Ground Task Force Warplanning System II (MAGTF II), Users Manual & Data Dictionary, Version 3.2, undated.

Dowsland, K. (1987). An Exact Algorithm for the Pallet Loading Problem. *European Journal of Operational Research* 31(1), 78-84.

Dowsland, K. (1990). Efficient Automated Pallet Loading. *European Journal of Operational Research* 44(2), 232-238.

Foote, W.C. (1993, Summer). Planning Reception, Beddown, and Support of Contingency Operations. *Air Force Journal of Logistics*, 17(3), 1-3.

Fortner, L.E. (1982, September). *A Methodology for CONUS APOE Reception Planning*. Wright-Patterson AFB, OH: AFIT.

Gehring, H., Menschner, K., & Meyer, M. (1990). A Computer-based Heuristic for Packing Pooled Shipment Containers. *European Journal of Operational Research* 44(2), 277-288.

George, J., & Robinson, D. (1980). A Heuristic for Packing Boxes into a Container. *Computers and Operations Research* 7(3), 101-105.

Hall, R. (1989). Vehicle Packing. *Transportation Research B* 23B(2), 103-121.

Han, C., Knott, K., & Egbelu, P. (1989). A Heuristic Approach to the Three-dimensional Cargo-loading Problem. *International Journal of Production Research* 27(5), 757-774.

Irving, J. (1992, October). *Unit Type Code (UTC) Life Cycle Study*. Maxwell AFB, Gunter Annex, AL: AFLMA

Ivancic, N., Mathur, K., & Mohanty, B. (1989). An Integer Programming Based Heuristic Approach to the Three-dimensional Packing Problem. *Journal of Manufacturing and Operations Management* 2(4), 268-298.

Larsen, O., & Mikkelsen, (1980). *An Interactive System for the Loading of Cargo Aircraft*. *European Journal of Operational Research* 4(6), 367-373.

Lloyd, B.A. & Zeck, W.Z. (1995, January). *The Enhanced Contingency Logistics Planning and Support Environment: The Vision*. Wright-Patterson AFB, OH: AL/HRCG.

Standard System Center (SSC). (1994a) *Seymour Johnson AFB Integrated Mobility Master Plan*. Maxwell AFB, Gunter Annex, AL: Directorate of Logistics Support Systems.

Standard System Center (SSC). (1994b) *Proposed BLSM II Acquisition Strategy*. Maxwell AFB, Gunter Annex, AL: Directorate of Logistics Support Systems.

Tsai, Russell D., Malstrom, Eric M. & Meeks, Howard D. (1988). A Two-dimensional Palletizing Procedure for Warehouse Loading Operations. *IIE Transactions*, 20(4), 418-425.

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